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SOUTHERN COMPANY

Energy to Serve Your World℠

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NL-04-2326

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D. C. 20555-0001

Joseph M. Farley Nuclear Plant Units 1 and 2
Response to Request for Additional Information Related to
Request to Revise Service Water Intake Structure Exemption From Fire Protection Requirements at Farley Nuclear Plant

Ladies and Gentlemen:

By letter dated August 28, 2003, Southern Nuclear Operating Company (SNC) submitted a request to revise the Service Water Intake Structure (SWIS) exemption from fire protection requirements at Farley Nuclear Plant (FNP). The exemption revision is part of SNC's comprehensive plan to respond to the NRC's concerns about Kaowool fire barrier material. The revised exemption will clarify SNC's fire protection licensing basis, delete unnecessary attributes of the exemption, and revise the remaining exemption attributes to remove references to Kaowool. NRC approval of the revision to the current exemption will satisfy the NRC's exemption requirements in 10 CFR 50.12. On June 25, 2004, the NRC submitted to FNP a request for additional information (RAI). Enclosure 1 provides the NRC questions and the SNC responses to those RAI questions. Enclosure 2 is a description of the SWIS fire model.

Modifications to the SWIS structure to support the revised exemption are planned to be completed by December 2005. Plant modifications to remove the need for lubricating oil from the Unit 2 booster pumps will be completed by December 2006.

SNC requests that the NRC approve the revised comprehensive exemption by December 15, 2005. Compensatory measures currently in place at the SWIS will remain until modifications to support the revised exemption request are completed.

(Affirmation and signature provided on the following page).

A001

Mr. L. M. Stinson states he is a Vice President of Southern Nuclear Operating Company, is authorized to execute this oath on behalf of Southern Nuclear Operating Company and to the best of his knowledge and belief, the facts set forth in this letter are true.

This letter contains no NRC commitments. If you have any questions, please advise.

Respectfully submitted,

SOUTHERN NUCLEAR OPERATING COMPANY

L. M. Stinson

Sworn to and subscribed before me this 28 day of December, 2004.

Notary Public

My commission expires:

NOTARY PUBLIC STATE OF ALABAMA AT LARGE
MY COMMISSION EXPIRES: June 10, 2008
BONDED THRU NOTARY PUBLIC UNDERWRITERS

LMS/JLS/sdl

Enclosures: 1. SNC Response to NRC Requests for Additional Information
2. SWIS Fire Modeling

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Joseph M. Farley Nuclear Plant Units 1 and 2
Response to Request for Additional Information Related to
Request to Revise Service Water Intake Structure Exemption From Fire Protection Requirements at Farley Nuclear Plant

Enclosure 1

SNC Response to NRC Requests for Additional Information

NRC Question 1

On Page B-7 of your submittal you state:

> "In addition, SNC determined that certain cables for MOVs that align the swing Service Water pump discharge valves no longer require reliance on Kaowool. Service water alignment procedures remove power from these valves, thus precluding spurious valve operation."

Is power removed from the MOVs prior to fire initiation, i.e., whenever Service Water is realigned, the MOVs are powered for the realignment and then, once realigned, have the power removed? How often are the pumps realigned and what is the time period during the realignment when power is provided to the MOVs? What is the probability (time-integrated frequency) of fire covering these time periods?

SNC Response:

The procedures for realignment of the swing Service Water pump are structured such that the discharge valves which provide train separation are powered only during the time required to correctly position the discharge valves. That is, the power supply breakers are closed by an operator in the Service Water Structure, the two valves are repositioned one at a time using the main control board handswitches, and the power supply breakers are opened. The on-service train alignment is changed approximately every two weeks to facilitate scheduled plant maintenance. Power is supplied to the valves for less than ten minutes during each train realignment evolution. Therefore, the valves would normally be powered for less than 260 minutes per unit per year or 520 minutes total per year. The generic fire frequency for the Service Water pumps is 8.00E-03/year per unit. The resulting probability of Service Water pump fire during a period when the discharge valves are powered is 3.96E-06 per unit.

NRC Question 2

On Page B–11 of your submittal you state:

> "Target damage was assumed to occur if the target surface temperature reached 700 ^{0}F ... The threshold damage condition for a target was a surface temperature of 700 ^{0}F."

On Pages B–12 and B-13 of your submittal you state:

> "A Unit 1 Service Water pump scenario was assumed to involve 22.5 gallons of Texaco Regal 68 lubricant, a Class IIIB combustible liquid ... The maximum number of pumps that could thus be damaged by a single fire is three (two by flame impingement and one by thermal radiation or one by flame impingement and two by thermal radiation). The temperature of any pump target of cable tray target located beyond this range would be less than 610°F."

Appendix F – Fire Protection Significance Determination Process (SDP), (Draft, February 2004), states the following in Section 6.2.3.3, "Task 2.3.3: Identify Nearest Ignition and Damage Targets:"

> It is worth noting that in the IPEEE, a commonly applied screening failure threshold for IEEE-383 qualified cables applied by licensees was 370°C (700°F) ... The 700°F value is recommended in the EPRI FIVE method (EPRI TR-100370), and appears again in the EPRI Fire PRA Implementation Guide (EPRI TR-105928). The original source cited for this value is the EPRI cable damage tests

reported in a series of Factory Mutual Research Corporation (FMRC) studies from the early 1980s (see in particular EPRI NP-1767, March 1981). The method used to estimate the cable "critical" threshold values cited in the original FMRC work, and repeated in FIVE, has since been discredited, and has been disavowed by FMRC (see letter, A. Tewarson of FMRC, to R. Kasawara of EPRI, 5/10/95). There appears little basis for the continued reliance on 700°F as a screening threshold for thermoset/qualified cables given the direct evidence of failures at substantially lower temperatures for a broad and common class of thermoset/qualified cable products. Recommended SDP Practice: A failure threshold of 330°C (625°F) is recommended for the generic class of thermoset cables.

What would be the impact when reassessing the potential damage to the pumps beyond the three-pump range mentioned above in light of the recommended reduced damage threshold of 625°F? In other words, what is the nature of the 610°F estimate? Is it an upper bound or mean value? If an upper bound, what is the confidence level and how robust is it? Sensitivity analyses may be appropriate to demonstrate robustness.

SNC Response:

The original calculation was a bounding estimate of the target surface temperature given the exposure conditions. Transient effects were ignored, though they were calculated. Peak values were used to determine the temperature response of all target sets. Since the results were bounding and the temperature was shown to be below the critical temperature recommended for thermoset cables (330°C [625°F]), the conclusions would not be altered by making this change.

Since the maximum temperature would be just under the critical temperature using the original approach, the calculation methodology was revised to reflect a more realistic exposure condition by using the transient results (i.e., smoke layer development) to calculate the target response to the assumed fire scenarios. A safety factor of two is applied to the emissive power of the flames in all cases. The more detailed calculation methodology is described fully in Enclosure 2 to NL-04-2326. The maximum expected fire scenario (MEFS) for the various targets was computed and it was determined that the maximum temperature of adjacent pump motor junction box targets would be about 315°C (600°F), and targets adjacent to these (i.e., second tier motor junction box targets) would be about 150°C (302°F). The exposure conditions for other targets were less severe. Adjacent pump motor junction box targets were previously shown to fail under the bounding assumptions; second tier targets were not assumed to fail but had a maximum surface temperature of 320°C (610°F), just under the recommended threshold value of 330°C (625°F).

A sensitivity analysis was performed on the ventilation conditions and the emissive power of the flame. It was found that the adjacent pump motor junction box targets could be heated to the critical temperature if the mechanical ventilation system operated and functioned normally for the duration of the fire (see response to NRC Question 18). It was also determined via the limiting fire scenario (LFS) that a 20% increase in the assumed emissive power (note that there is already a safety factor of two associated with this value) could result in failure of adjacent pump motor junction boxes. As a result, these targets are assumed to fail, as was the case in the original analysis. Other targets were not as sensitive to the flame emissive power, requiring a 150% or greater increase for failure to occur. The complete results of the sensitivity analysis, including the parameters evaluated and the degree to which they influence the target surface temperature, are summarized in Enclosure 2 to NL-04-2326.

In addition to a sensitivity analysis, a LFS was determined for each scenario considered. It was found that a heat release rate increase of two to five times above the MEFS values is required to cause a target to fail that otherwise would not. The LFS was determined for other aspects of the analysis, such as the emissive power of the flame (two to three times the MEFS) and the combined effects of a smoke layer-thermal plume exposure (four times the MEFS heat release rate and five times the MEFS mass). Refer to Enclosure 2 to NL-04-2326 for details of the LFS calculations.

NRC Question 3

On Page B-14 of your submittal you state:

> "The fire risk analysis focused only on elements of the SWIS that had been or were proposed to be changed from the current licensing basis. These elements were associated with pump/motor lubricant fires (one for each pump or ten cases in all). The risk analysis determined that a conservative estimate of the CDF associated with the ten cases would be approximately 6.5E-07/yr per unit."

Presumably, each scenario assumes one of the following per unit:

1) Fire in pump A or B, damaging the other pump and nearby pump C. Pumps D and E fail from non-fire causes (2 scenarios per unit);
2) Fire in pump C, damaging pumps B and D. Pumps A and E fail from non-fire causes (one scenario per unit);
3) Fire in pump D or E, damaging the other pump and nearby pump C. Pumps A and B fail from non-fire causes (2 scenarios per unit).

The three pumps failed by the fire are assigned the common-cause failure frequency of that of the fire. The remaining two pumps are then assumed to fail randomly from non-fire causes. For these two pumps, was the possibility of both being out-of-service for maintenance, etc., considered, assuming this is not precluded by Technical Specifications? Was common-cause failure of these two pumps addressed, assuming other than fire-induced mechanisms (e.g., silting)? If so, how was common-cause failure modeled (e.g., MGL, alpha-factor, etc.)? Was the CDF for each scenario the same (i.e., 6.5E-07/yr * 1/5 = 1.3E-07/yr), or were they different? If different, what accounted for the asymmetry?

SNC Response:

The fire scenarios used for the analysis were as follows:

1) Fire in pump A or B damaging the other pump and nearby pump C. Pump D in maintenance and Pump E fails from non-fire causes (one scenario per unit);
2) Fire in pump A or B damaging the other pump and nearby pump C. Pump E in maintenance and Pump D fails from non-fire causes (one scenario per unit);
3) Fire in pump C, damaging pumps B and D. Pumps A and E fail from non-fire causes (one scenario per unit);
4) Fire in pump C, damaging pumps B and D. Pump A fails from non-fire causes and Pump E in maintenance (one scenario per unit);
5) Fire in pump C, damaging pumps B and D. Pump A in maintenance and Pump E fails from non-fire causes (one scenario per unit);
6) Fire in pump D or E, damaging the other pump and nearby pump C. Pump A in maintenance and Pump B fails from non-fire causes (one scenario per unit).
7) Fire in pump D or E, damaging the other pump and nearby pump C. Pump A fails from non-fire causes and Pump B in maintenance (one scenario per unit).

For the purposes of the discussion in the submittal, scenarios 3, 4, and 5 were counted as a single scenario because they all originate with a fire in pump C. However, the actual CDF calculation considered these as separate scenarios.

The possibility of two pumps being out-of-service at the same time for maintenance was not included in the analysis because planned maintenance on more than one pump is not allowed under existing plant administrative procedures which preclude entry into an LCO for planned maintenance on systems having a swing pump (i.e., the component cooling, charging, and service water systems). The only scenario involving random failure of two pumps not affected by fire is scenario 3. For this case, the probability of a common-cause failure of the two pumps not affected by the fire was included using the MGL method with a probability of 2.75E-07.

The CDF for each of the seven scenarios was as follows:

Scenario Number	CDF (per year)
1	1.34E-07
2	1.34E-07
3	2.08E-08
4	4.48E-08
5	4.48E-08
6	1.34E-07
7	1.34E-07

The CDF contributions for scenarios 3, 4, and 5 are lower because these scenarios have a higher probability that RCP seal cooling is not impacted. Therefore, the conditional core damage probabilities for these scenarios are lower.

NRC Question 4

On Page B-14 of your submittal you state:

> "The scope of the analyses that were performed for this analysis included a re-analysis of the Service Water system performance. This re-analysis concluded that a single Service Water pump per unit was sufficient to satisfy the system performance requirements. The re-analysis results were integrated into the PRA Model by altering the number of Service Water pumps per train that was required for system success from two to one."

On Page B-19 of your submittal you state:

> "An integrated risk assessment shows that safe shutdown can be achieved even if no credit is taken for the Kaowool raceway enclosures. This finding is also based, in part, on a re-determination of the safe shutdown success criterion, using traditional thermal-hydraulic techniques. The exemption should be revised not only to eliminate reliance on Kaowool but also to recognize the new success criterion."

Did this re-analysis of Service Water system performance address the Service Water requirements during a core damage scenario, or did it consider only reaching and maintaining hot shutdown for a limited period? Were there any differences between units? If so, what accounted for the asymmetry? What constituted the "traditional thermal-hydraulic techniques" (e.g., MAAP) that were used to verify the less limiting performance requirement during a core damage scenario? What was the sensitivity of the PRA results to the modeling assumption of one vs. two required Service Water pumps?

SNC Response:

The original Service Water success criteria were based on the requirement for two pumps in a single train for support of systems following a Loss of Offsite Power or ECCS actuation. However, this same success criteria was also conservatively applied to the Loss of Service Water Train special initiating event fault tree and the system fault trees for RCP seal cooling.

Plant experience with an actual loss of two of three Service Water pumps in the train supplying RCP seal cooling during plant operation showed that one pump could maintain RCP seal support conditions, and that the plant could maintain power operation with three of five Service Water pumps. Therefore, the criteria for the Loss of Service Water Train special initiating event was changed from loss of two of three pumps to loss of three of three service water pumps in the on-service train, and from loss of one of two pumps to loss of two of two pumps in the non-on-service train. The success criteria for events involving Loss of Offsite Power or ECCS actuation (due to direct initiating event or consequential LOCA) was not changed and requires two operable pumps in a single train.

Since Appendix R requires that the plant be capable of reaching safe-shutdown conditions following the fire, thermal-hydraulic analyses were performed using models of the Service Water system (using KY Pipe) and Component Cooling Water heat exchangers (using a BALANCE model created by Bechtel) to confirm that a single service water pump could provide sufficient decay heat removal from plant systems required to reach cold shutdown. The analysis showed that safe shutdown conditions could be achieved with a single service water pump, assuming secondary heat removal via the Auxiliary Feedwater System was available and no LOSP or ECCS actuation had occurred. However, the cooldown rate would be reduced and the plant would have to be maintained in hot shutdown for 72 hours prior to entering cold shutdown.

There is no difference in the success criteria between the units.

Since the change in success criteria was viewed as a removal of conservative assumptions from the IPE, no sensitivity analyses related to the modeling assumptions of one vs. two required Service Water pumps were performed. However, SNC evaluated the fire risk to eliminate reliance on Kaowool in the August 28, 2003 submittal, Attachment B, which stated:

> "Regulatory Guide 1.174 and NFPA 805 specify that the risk associated with a plant change is determined by considering the change in CDF and large early release frequency (LERF) that result from the plant change. These changes in CDF and LERF are calculated by comparing the CDF and LERF values for the entire fire area before and after the change to ensure that all contributors to risk are included. The fire risk analysis focused only on elements of the SWIS that had been or were proposed to be changed from the current licensing basis. These elements were associated with pump/motor lubricant fires (one for each pump or ten cases in all). The risk analysis determined that a conservative estimate of the CDF associated with the ten cases would be approximately 6.5E-07/yr. per unit."

This placed the proposed change in Region III of the Regulatory Guide 1.174 acceptance criteria for CDF.

NRC Question 5

On Page B-15 of your submittal you state:

> "The plant PRA model was modified to take advantage of recent vendor data related to RCP seal performance. The specific data is related to seal performance given loss of motor bearing cooling."

Did this modification utilize the WOG2000 RCP seal leakage model? If so, what version was used? Whatever model was used, how did the results compare with other RCP seal leakage models, such as Rhodes? What was the sensitivity of the PRA results, to the model change? How much of this sensitivity was reflected in the PRA performed for this exemption request?

SNC Response:

The modification referred to involved the modeling of RCP seal failure as a result of loss of RCP motor bearing cooling, not the model for loss of RCP seal cooling. The SNC PRA model developed for the IPE and subsequent revisions conservatively included a failure of the RCP Seals due to RCP vibration as a direct consequence of a loss of RCP motor bearing cooling. Information provided to SNC at the time of the SWIS analysis and later included in WCAP-16141, "RCP Seal Leakage PRA Model Implementation Guidelines for Westinghouse PWRs," revealed that Westinghouse had studied actual loss of RCP motor bearing cooling events in the industry and determined that RCP seal performance is unaffected by the loss of motor bearing cooling. Even though complete removal of the RCP seal failure on loss of RCP motor cooling was justified by the new information, the analysis for this exemption request was performed assigning a conservative conditional probability of 0.10 for RCP seal failure assuming loss of RCP motor cooling and no loss of RCP seal cooling.

The model used for RCP seal LOCA in the Revision 5 PRA model is based on information contained in NUREG/CR-4550, Volume 2. However, while some models have interpreted the NUREG/CR-4550 data to mean that seal damage will not occur prior to 90 minutes, the Farley model assumes that the increased seal leakage will begin at 15 minutes after the loss of all RCP seal cooling. The 15 minute time for initiation of increased leakage was chosen based on information in WCAP-10541 which indicated the seals would start heating up within 10 to 15 minutes of a loss of all seal cooling. Since there is some time after the initial loss of seal cooling until the seals are expected to be damaged, the Farley model does credit recovery of RCP seal injection using the standby train of Component Cooling Water (CCW) and charging. This recovery requires only that the operators start the standby CCW and charging pumps and align the charging pump suction to the RWST to ensure cool water is provided to the seals. All of these actions are included in operator procedures for response to a loss of RCP seal cooling and are performed from the main control room. A recovery time window of 10 minutes is assumed for the Human Reliability Analysis (HRA).

To simplify the linked fault tree structure, loss of RCP seal cooling events (due to loss of support systems or SBO) are binned into two treatments based on the expected RCP seal leakage rate. Those sequences with leakage rates of 21 gpm per pump (assigned a probability of 0.811 based on the 5.5 hour leakage probabilities for new o-rings from NUREG/CR-4550, Volume 2, Table 5.4-1) are expected to progress in the same manner and require the same mitigation equipment as a general transient. Those sequences with leakage rates greater than 21 gpm per pump (assigned a probability of 0.189) are expected to progress in the same manner and require the same mitigation equipment as small LOCA events. For the purposes of analyzing time to core uncovery for the events with leakage rates greater than 21 gpm per pump, the maximum expected leakage rate of 480 gpm per pump was used.

The current Farley seal LOCA model assumes that the increase in RCP seal leakage occurs two minutes later than recommended in the NRC SER for the WOG 2000 model (WCAP-15603, Revision 1-A, "WOG 2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs"). However, since the recovery of seal injection is only credited if it occurs within 10 minutes, the difference in the timing of the increased seal leakage has no impact on the SWIS analysis. Further, the combination of the greater than 21 gpm per pump leakage rate probabilities into a single binning event serves to remove credit for the third stage seal as recommended by Rhodes and as recommended in the NRC SER for WCAP-15603. The probability assigned to the 21 gpm leakage rate is slightly higher than that assigned by Rhodes (0.811 vs. 0.780). A sensitivity case for Unit 1 was run to assess the impact of this difference.

The impacts on the Unit 1 CDF for each fire scenario due to the reduction in the probability of RCP seal failure following a loss of RCP motor cooling and due to application of a different RCP seal leakage probability than that recommended by Rhodes are as follows:

Fire Scenario	CDF per year in Original Submittal	CDF per year Assuming RCP Seal Failure on Loss of Motor Cooling	CDF per year Assuming Rhodes Failure Probabilities
1	1.34E-07	2.38E-07	1.48E-07
2	1.34E-07	2.38E-07	1.48E-07
3	2.08E-08	2.20E-08	2.08E-08
4	4.48E-08	9.69E-08	4.87E-08
5	4.48E-08	9.69E-08	4.87E-08
6	1.34E-07	2.38E-07	1.48E-07
7	1.34E-07	2.38E-07	1.48E-07
Total	6.46E-07	1.17E-06	7.10E-07

NRC Question 6

On Page B-15 of your submittal you state:

> "The LERF associated with the proposed change is negligible given the acceptance criteria of Regulatory Guide 1.174."

The Large Early Release Frequency (LERF) would be bounded by the Core Damage Frequency (CDF), indicating a maximum possible LERF of 6.5E-07/yr per unit. Assuming a typical probability of no more than 0.1 for a large early release given core damage, this would suggest a LERF of ~6.5E-08/yr per unit. This would fall in region III of the LERF acceptance guidelines in Regulatory Guide 1.174. This would be in the same region as the CDF calculation, therefore some additional detail that builds on the CDF result would be expected in the exemption request regarding the LERF. Was the LERF truly "negligible" (i.e., <1E-8/yr per unit), or was it also a Region III result like the CDF?

SNC Response:

Fire in the SWIS will not result in a direct Containment Bypass or ISLOCA. Therefore, the only contribution to LERF as a result of a fire in the SWIS would be the result of core damage in combination with containment failure. The Farley design incorporates a Large, Dry Containment. The IPE concluded that early containment failure due to Direct Containment Heating, Hydrogen Combustion, or Steam Explosions are not likely. Therefore, the contribution to LERF from a SWIS fire is the result of core damage combined with failure of containment isolation. The conditional probability of containment isolation failure (crediting only check valves and fail closed air-operated valves) is 2.13E-4. This resulted in a total LERF contribution from the seven SWIS fire scenarios analyzed for Unit 1 of 1.38E-10/yr per unit which was judged to be negligible with respect to the acceptance guidelines of Regulatory Guide 1.174.

NRC Question 7

On Page B-18 of your submittal you state:

"Nine PRA elements were judged by the peer review to have findings that resulted in their being considered 'Contingency Grade 3.' A 'Contingency Grade 3' reverts to a 'Grade 3' when items noted in the evaluation of the element are resolved. Such pending items are classified as one of four degrees of significance. None of the pending items noted in the Plant Farley PRA evaluation were judged to be of a level of significance to require prompt resolution to ensure the technical adequacy of the PRA for this specific application."

Were there any Contingent Grade 3 sub-elements or elements that could impact the PRA for this exemption request still pending resolution at the time of the analysis? If so, were any at an "A" or "B" level of significance? If so, please elaborate.

SNC Response:

There were no Category A findings resulting from the Farley peer review. Issues with Facts and Observations classified as significance level "B" which were unresolved at the time of the SWIS analysis and could potentially impact the SWIS analysis are addressed below:

Observation SY-02

Issue: This element asks if the model matches the as-built, as-operated plant, including information in the AOPs and EOPs. A brief review was performed, focusing on the system models for electric power, CCW, SW and AFW. The model fidelity with plant systems as described in available documentation generally seemed good, but there were a number of apparent differences which should be resolved.

(5.) CCF of all service water pumps should be added to the model. It was not clear to the reviewers if these pumps are all of identical manufacture, but there are many common elements associated with their installation and use. The model should be reviewed to see if there are other systems where common-cause failures need to be applied to n of n components (such as CCW).

Effect on SWIS analysis: Since the SWIS analysis assumed three to five pumps were failed as a result of the fire, this issue has no effect on the analysis. As noted in the response to question 3, common-cause failure of pumps unaffected by the fire was included where appropriate.

Observation SY-07

Issue: It is standard practice in the Farley PRA to not model any common-cause between standby and operating components. While this practice may have been acceptable during the IPE time period, the INEEL CCF database provides some evidence of common-cause dependencies between standby and operating components. Current practice suggests that you should identify and model common-cause failures which could prevent all similar components in a system from performing their intended function (for example: CCW pumps, SW pumps).

Effect on SWIS analysis: Since the SWIS analysis assumed three to five pumps were failed as a result of the fire, this issue has no effect on the analysis. As noted in the response to question 3, common-cause failure of pumps unaffected by the fire was included where appropriate.

Observation DA-02

Issue: The common-cause failure probabilities are referenced to a 1990 data source. Given the extensive research on common-cause events sponsored by the NRC since the time of the IPE, a more up-to-date common-cause data source should be used. Some of the common-cause failure probabilities used in the PRA are significantly different than those from a recent generic data source, NUREG/CR-5497. It is recognized that the values in that document are unscreened values and are likely to be reduced by NUREG/CR-4780 screening process that Farley employs.

Effect on SWIS Analysis: As noted in the response to NRC Question 3, the SWIS analysis included common-cause failure of Service Water pumps not affected by the fire where appropriate. The common-cause factors used for the analysis were based on the MGL methodology used for the IPE. Since the completion of the SWIS analysis, SNC has completed work toward updating the common-cause analysis to the Alpha methodology using the latest INEEL common-cause database. Results from this update show that the value of the basic event for common-cause failure of two Service Water pumps which affects this analysis will decrease from 2.75E-07 to 2.69E-07 in the next revision of the Farley PRA model. This is due to the fact that the original analysis applied the same factors for failure to run and failure to start whereas the updated analysis applies unique factors for each failure mode. Therefore, this observation has no effect on the conclusions reached for the SWIS Fire Protection Exemption.

Observation DA-05

Issue: There are two diesel generator common-cause groups. One set includes the 1C and 2C diesel generators and the other set includes the 1B, 2B, and the 1/2-A diesel generators. These two sets are apparently of different design. However, there are other factors that should be considered in establishing common-cause groups, including common maintenance crews, common I&C technicians, similar procedures, common fuel oil, etc. It is recognized that, in the past, it was not common practice to consider common-cause failures where substantial design differences existed. The basis for such practice lies with the practicality of implementation. In the case of the onsite emergency AC sources, no such implementation barriers exist.

Effect on SWIS Analysis: Since it is assumed that all of the fire scenarios for the SWIS will result in insufficient support for consequential LOSP conditions, this observation has no impact on the analysis performed for the SWIS Fire Protection Exemption.

Observation DA-07

Issue: The loss of offsite power non-recovery curves were developed during the IPE based on data from NUREG-1032. The curves have not been updated for the PRA. NUREG/CR-5496, "Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1980 - 1996, is a more up-to-date data source.

Effect on SWIS Analysis: Since it is assumed that all of the fire scenarios for the SWIS will result in insufficient support for consequential LOSP conditions, this observation has no impact on the analysis performed for the SWIS Fire Protection Exemption.

The following observations all deal with the treatment of human errors and are addressed by a single response:

Observation HR-01

Issue: The IPE HRA calculation developed HEPs for specific plant response trees. After the conversion to CAFTA, the linked fault tree allows them to be applied to other events. For example, HEP 1DGOPOPERDG1CHDE indicates that it was evaluated for use in the SBO event tree. When the event is followed up the single top CDF tree, it is also found to be used in other event trees such as ATWS. There is no documentation that the calculation is valid for event trees other than SBO.

Observation HR-04

Issue: There was no indication that miscalibration errors or common-cause miscalibration errors were included. A reference was found that said miscalibration was ignored, because the high and low miscalibrations would cancel out. This reasoning does not follow.

Observation HR-05

Issue: The HRA uses two different methods for calculating HEPs - the Success Likelihood Index Method (SLIM) and the Technique for Human Error Rate Prediction (THERP). The implementation of these HRA methods is problematic for the following reasons:

1) Although several groups of plant Operations/Training personnel were involved in the assignment of SLIM weighting factors for the PSFs, this activity appears to have been dominated by two individuals who alone did the assignments for 1/3 of the HEPs and, in conjunction with a third individual, did the assignments for another 1/3 of the HEPs. The basis of the method assumes that the assignments would be done by a larger panel of experts.

2) The validity of the SLIM anchor points could not be verified during this review because the source is not identified in the HRA notebook, and the referenced Westinghouse calculation note which contains the details regarding the anchor point source is on microfiche and was not readily available for review.

3) The THERP calculations contain 0.1 multipliers for operator training/qualifications in both the diagnosis and execution portions of the calculation. They also contain a 0.1 multiplier for a "slack time recovery." These multipliers are not described in THERP and there is no justification for their use.

Observation HR-09

Issue: There was little evidence of plant specific analysis to support the timing of the HRA quantification. For each HEP, timing constraints were established but the basis for these constraints was not referenced. It appears that many of the timing constraints are generic estimates or screening values.

Effect on SWIS analysis: The human error probabilities used for the major operator actions in the Farley PRA model have been compared with those used by other Westinghouse Owners Group plants, the Checklist for Technical Consistency in a PSA Model contained in the EPRI PSA Applications Guide (TR-105396), and have also been reviewed as part of the NRC benchmarking effort for the Significance Determination Process. No significant differences have been identified in these comparisons. Therefore, these issues are expected to have little impact on the total core damage frequency and therefore will not affect the conclusions of the SWIS Fire Protection Exemption request.

NRC Question 8

On Page B-15 of your submittal you state:

"The results of the risk assessment show a conservatively estimated risk increase... The Farley Nuclear Plant does not have an updated fire risk assessment. The available analysis is the Fire IPEEE... Although a comprehensive update and upgrade of the plant PRA has not been performed, these estimates are sufficient to conclude that the proposed change is within the Region III limits."

Typically, an internal events PRA does not include fire-related failures of components already modeled for the internal events analysis or fire-related failures of components that would be credited in an internal fire PRA. The effect of the first exclusion can be non-conservative, in that additional failure modes are excluded, while the exclusion of the latter can be conservative because additional credit for means of avoiding core damage, identified only through fire safe-shutdown analyses, are not modeled. Ideally, the overall effect is that fire CDF estimates developed from an internal events PRA will be conservative relative to the fire CDF that would be estimated from a combined internal events and fire PRA. Please describe, at a high level, the technical approach by which the Farley fire CDF analysis ensured the results were conservative. For example, a fire in an area was assumed to fail/spuriously actuate all susceptible components (e.g., either via presence of the components themselves or their power/control cables) as modeled in the internal events PRA, with the appropriate frequency of a non-suppressed fire in that area superimposed on the corresponding initiating events (e.g., loss of offsite power) that would result from the fire.

SNC Response:

The determination of fire impacts for the SWIS involved plant walkdowns and fire modeling as described in Pages B-8 through B-13 of the exemption request. Following identification of the fire scenarios to be considered, a new initiating event representing each scenario was added to the internal events PRA model. Although there is no direct reactor trip initiated due to a fire in the SWIS, it was assumed that the loss of multiple Service Water pumps as a result of the postulated fire impacts would result in a manual reactor trip. Therefore, the fire initiating events were added to the internal events PRA model under gates representing a reactor trip initiating event and under gates representing failure of each impacted component.

The internal events PRA model does credit some equipment for which the cable routing is not documented in the Appendix R Raceway Database. Therefore, a global assumption is made that the equipment in the internal events PRA model which is not included in the Appendix R Raceway Database will be failed for any fire. The specific equipment not included in the Appendix R analysis is:

- Instrument Air Compressors A and B
- Containment Fan Coolers
- Containment Spray System
- Steam Dumps
- Main Feedwater Pumps
- Condensate Pumps
- Service Water from the opposite unit
- Instrument Air from the opposite unit

Failure of these components is conservative for the SWIS analysis because the SWIS is separated from the plant structures containing these components and because Service Water support would be adequate for components such as the instrument air compressors and condensate pumps in the postulated SWIS fire scenarios.

Following addition of the representative fire events to the internal events PRA model, the model was quantified assuming each of the two possible on-service train alignments for each scenario. The resulting Conditional Core Damage Probability (CCDP) for each scenario was then combined with the Fire Ignition Frequency for each scenario to calculate the Core Damage Frequency.

NRC Question 9

Fire protection for nuclear power plants uses the concept of defense in depth to achieve the required degree of reactor safety by using echelons of administrative controls, fire protection systems and features, and safe shutdown capability. These defense-in-depth principles are aimed at achieving the following objectives.

- To prevent fires from starting,
- To detect rapidly, control, and extinguish promptly those fires that do occur, and
- To provide protection for structures, systems, and components important to safety so that a fire that is not promptly extinguished by the fire suppression activities will not prevent the safe shutdown of the plant.

On Page B-3 of your submittal you provide a general overview of the Service Water Intake Structure (SWIS) and the fire suppression and detection systems provided.

Based on the description in your letter dated August 28, 2003 and our previous Safety Evaluation (Enclosure 2 to letter dated December 29, 1986 from NRC to Alabama Power Company), it is our understanding that the SWIS Fire Area 72 has the following fire protection systems: (Please confirm our understanding of the fire protection systems provided in Fire Area 72 and provide any necessary clarifications.)

1. Smoke detection throughout Fire Area 72.

   Clarify and confirm that all portions of Fire Area 72 in the SWIS are protected by smoke detectors.

2. Preaction 'spray' system protecting the service water pumps.

   Is this a separate preaction system from the area wide preaction system? If so, please provide a summary description.

3. Area wide preaction sprinkler system protecting the area in the strainer pit beneath the pump deck.

   Describe the extent of coverage for this system. Does this system extend underneath the pump deck's approximate 12' overhang above the strainer pit?

4. Preaction sprinkler system protecting the safe-shutdown cabling in the upper northeast corner of the service water pump room.

   Is this a separate preaction system from the area wide preaction system? If so, please provide a summary description.

5. Portable fire extinguishers located throughout Fire Area 72.

   Please confirm that portable fire extinguishers are provided in Fire Area 72.

6. Two fire hose/hydrant houses located directly outside of the SWIS within the security fence.

   Please confirm that the hose houses contain adequate lengths of hose such that all areas of Fire Area 72 can be reached with an effective hose stream.

SNC Response:

1. Smoke detection throughout Fire Area 72.

   A smoke detection system that gives local alarm and annunciates in the control room is installed in Fire Area 72. Forty Pyrotronics high voltage ionization detectors are provided at the SWIS. Detectors are located in all areas of the SWIS including the pump motor area, under the pump motor deck, in the battery rooms, in the stairways, and in the strainer area. Activation of any detector trips the clappers for all three preaction sprinkler systems.

2. Preaction 'spray' system protecting the service water pumps.

The preaction spray system protecting the service water pumps is a separate system from the area wide preaction system. General area coverage is provided by preaction systems 1SW-111A and 1SW-111B. Preaction sprinkler system 1SW-111 provides suppression coverage in the area of the SW Pumps only. Heat collectors have been installed to prevent cold soldering because another sprinkler nozzle is installed above (systems 1SW-111A and 1SW-111B). Preaction system 1SW-111 has been installed for local application protection per the NFPA 15 code for special hazard philosophy to provide water spray onto the SW pumps. Detection system 1SW-111 preactivates sprinkler systems 1SW-111, 1SW-111A, and 1SW-111B.

3. Area wide preaction sprinkler system protecting the area in the strainer pit beneath the pump deck.

   Two other preaction systems provide coverage to the entire pump deck, the area in the strainer pit beneath the pump deck, and to safety-related cabling in the upper northeast corner of the service water pump room. These systems are tripped by any of the detectors in the area.

4. Preaction sprinkler system protecting the safe-shutdown cabling in the upper northeast corner of the service water pump room.

   The preaction system protecting the safe-shutdown cabling in the upper Northeast corner of the SW Pump Room is not a separate system from the area wide preaction system. Sprinkler system 1SW-111A provides suppression coverage to the Eastern half of the pump deck, the strainer pit beneath the pump deck, and to cable trays near the ceiling in the Northeast corner of the area.

5. Portable fire extinguishers located throughout Fire Area 72.

   Portable fire extinguishers consisting of two 15 lb. CO2 extinguishers and six 20 lb. dry chemical extinguishers are provided throughout Fire Area 72.

6. Two fire hose/hydrant houses located directly outside of the SWIS within the security fence.

   The two hose stations shown on A508651 sheets 7 and 8 (legend on sheet 2) each contain 75 feet of 1 1/2 inch hose. The hose houses located outside the SWIS building each have 250 feet of 2 1/2 inch hose and 100 feet of 1 1/2 inch hose. In addition, the Fire Brigade Van contains 1000 feet of 2 1/2 inch hose and 400 feet of 1 1/2 inch hose. Therefore, all areas of Fire Area 72 can be reached with an effective hose stream.

NRC Question 10

Fire protection for nuclear power plants uses the concept of defense in depth to achieve the required degree of reactor safety by using echelons of administrative controls, fire protection systems and features, and safe shutdown capability. The first objective in the concept of defense-in-depth for fire protection is:

"To prevent fires from starting"

Several areas of your submittal discuss transient combustibles; and some of the fire modeling accounts for specific quantities and types of in-situ combustibles; and other areas of the submittal discuss the need for administrative controls to limit the amount of lubrication oil during maintenance activities in the SWIS. Given the very specific transient and in-situ combustibles discussed, please describe the combustible and ignition controls that will be put in place to ensure that the first objective of defense-in-depth is maintained; and to ensure that the described margins between a Maximum Expected Fire Scenario (MEFS) and a Limiting Fire Scenario (LFS) are maintained (see pages B-12 through B-14); and to ensure that any combustibles due to maintenance activities (e.g., pump oil change-out that may cause double the amount of assumed oil to be in the area) are adequately controlled.

Describe any designated storage areas in the SWIS and the amounts and types of combustibles in those storage areas. If there are any designated storage areas in the SWIS containing combustibles, describe how the fire modeling considered these combustibles (as an intervening combustible and/or as a primary combustible). The staff is concerned with 'non-target' and secondary combustibles that may propagate fire from the initiating source to the target cables.

SNC Response:

- Enhanced transient combustible controls will be implemented in the SWIS, with particular emphasis on the northeast corner and the Service Water pump deck.
- Configuration control will be maintained (from a fire protection program perspective) over the type and quantity of lubrication oil used in the Service Water pump motors.
- Precautions will be implemented to limit the amount of lubricant in the vicinity of the Service Water pumps during lubricant changes by removing the drained lubricant from the area prior to bringing the new (unused) lubricant into Fire Zone 72A.

NRC Question 11

Page B-9, Paragraph under, "Initial Assessment," states, "Three fire scenarios required a more detailed evaluation in order to make an adequate preliminary assessment of fire risk in the SWIS. Other fire scenarios were determined to not contribute to the change in risk being assessed."

Provide a summary description of the 'other fire scenarios' and the bases for the determination that these other fire scenarios do not contribute to the change in risk.

SNC Response:

The general approach was to identify the most likely fire scenarios that could impact one or more targets. As summarized in Enclosure 2 to NL-04-2326, these scenarios are:

1. A transient fire in the northeast corner of the strainer pit.
2. A lubricant fire involving the contents of the largest Unit 1 service water pump reservoir.
3. A lubricant fire involving the contents of the largest Unit 2 service water pump reservoir.

Fire scenarios that were considered in the SWIS were based on in-situ combustible material or transient fuel packages and are summarized as follows:

- Lubricant/grease fires
- Class A transient fires
- Motor fires
- Cable tray fires

- Transient fuel packages associated with maintenance activities

Lubricant and grease fires are in-situ fuel packages. The most significant quantity of lubricant is associated with the Unit 1 service water pumps; the second most significant quantity of lubricant is associated with the Unit 2 service water pumps. Both sources are evaluated in detail relative to their potential to damage targets as noted above. Other locations where there is oil or grease involve smaller quantities and greater target separation. Since it was determined that the MEFS does not result in target damage, and that the LFS is substantially greater than the MEFS, other lubricant/grease fires would not impact the risk.

Power and control cables have jacket and insulation materials that are IEEE-383 qualified and utilize thermoset materials. Eight PVC cables were identified that are being used as instrument cables for cameras; portions of these cables will be removed to meet the fire model analysis. Per the most recent edition to the Fire Protection SDP, thermoset or IEEE-383 qualified cables are not assumed as ignition sources provided proper current limiting provisions are provided. Thus, cable trays are fuel packages if ignited by another source fire. Where cable trays are direct targets, ignition is not an applicable criterion since damage occurs prior to ignition. This effectively eliminates these trays from concern as an in-situ fuel package. Trays that are located over the strainer pit that are not targets are located at the same elevation as or higher than the target cable trays. This means that source fires that do not damage the target would not ignite these trays, regardless of the fire location. This eliminates these trays from concern as an in-situ fuel package.

The last group of trays that are not targets are generally located north of the service water pumps over the pump deck. These trays are located at the same elevation or higher than the target raceways against the east wall of the SWIS. This fuel package was eliminated because the heat release rate is bound by the pump fires and self propagating horizontal cable fires involving IEEE-383 cables is not postulated in accordance with the SDP guidance.

Transient fuel packages were evaluated where they would have the most impact. Other locations are further from the required target sets and are therefore bound by the scenarios evaluated. Since it was determined that the MEFS does not result in target damage, and that the LFS is substantially greater than the MEFS, other transient fuel package fire locations would not impact the risk.

A motor fire (windings) has significantly lower heat release rate than the postulated lubricant fires as summarized in the most recent edition of the Fire Protection SDP. These scenarios are bound in all respects by the lubricant fire. Since it was determined that the MEFS based on a lubricant fuel package does not result in target damage, and that the LFS is substantially greater than the MEFS, the motor fires would not impact the risk.

Transient fuel packages associated with maintenance activities will be controlled via procedural changes (see response to NRC Question 10).

The evaluation of the 'other fire scenarios' concluded that the MEFS would not have resulted in target damage. In addition, the assessment for LFS determined that substantial margin exists. Given these conditions, a risk quantification for the non-fire case would provide the same result as the quantification for the postulated fire case for these fire events. Therefore, since the results are the same, there is no change in risk due to those fire events.

NRC Question 12

Page B-9, Scenario 1 states that "A transient fire was considered to be the bounding fire in this area because of a lack of in-situ ignition sources and combustible material." Provide a summary basis for this statement considering that the cable jacketing/insulation itself is combustible.

SNC Response:

In this scenario the cable insulation is the target. There are no intervening cable jacketing/insulation materials between the floor and the cable trays of interest.

NRC Question 13

Page B-1 states that the SWIS is located about half a mile from the nuclear power block and its support buildings. Describe operator and fire brigade response to a fire alarm or to a fire suppression system actuation alarm in the SWIS. Specifically, describe operator response upon receipt of a fire alarm signal; how manual fire fighting response is planned considering the distance from the main power block; how manual fire fighting protective gear (bunker gear, SCBA, extra air supply, etc.) is ensured at the scene and how fire brigade members are transported to the SWIS.

SNC Response:

Upon receipt of an alarm, the Control Room would dispatch the Fire Brigade to the SWIS. The five person Fire Brigade would drive to the SWIS in the Fire Brigade Van. If requested by the Fire Brigade Leader, Maintenance would drive the Fire Tanker Truck to the SWIS. Turnout gear, SCBA packs, extra SCBA cylinders, and fire fighting equipment are contained in the Fire Brigade Van. Normally, the Fire Brigade Leader would drive the van while the other four members donned their turnout gear. The Fire Brigade Leader would then don turnout gear after arriving at the SWIS. The Control Room would dispatch extra SCBA cylinders to the SWIS as required. One Fire Brigade drill is conducted for each shift (6 shifts) on a quarterly basis to various areas of the plant. Acceptable response time is up to 17 minutes.

NRC Question 14

Two out of the three fire scenarios discussed in the submittal involve oil fires. Curbs are described in the submittal to contain oil spills (therefore, curbed volumes are limited). Describe how the fire brigade plans to fight a lube oil fire in the SWIS. Considering there is an automatic water based suppression system in the SWIS and the fire brigade has hose houses available, describe how the potential of oil spreading over the curbs due to sprinkler system or fire fighting water has been considered. Does the fire brigade have a readily available supply of foam and corresponding fire fighting equipment?

SNC Response:

The curbed areas where the liquid pools have a sufficient volume to contain all combustible liquid that could be involved. There are two conservative assumptions for the scenario to occur:

1. The liquid must pool behind the pumps (thereby exposing the junction box targets); and

2. The floor drains in the curbed region do not remove lubricant (i.e., they are ignored).

Though the floor is sloped toward the rear of the pumps, the elevation of the curbing is several inches greater than the maximum floor elevation within the curbed area. This means that as the liquid volume increases, the pool would expand to the front area of the pump. Once this occurs, the liquid is free to enter the drain areas and flow off the pump deck into the service water pit.

If the sprinkler system actuates, the additional volume of liquid in the curb area would behave as described above, rather than spill over the edge of the curbing. The assumption that the lubricant remains behind the pump is made so as to generate a conservative and bounding estimate of the fire duration. Such an assumption covers slow leaks as well as catastrophic failures. An added benefit of sprinkler system actuation is the cooling effect on the targets. While the water may cause the pool to spread and expand to the front of the pump (and away from targets), the water would be cooling nearby targets and could possibly prevent failure of adjacent pump motor junction box targets.

The impact of the floor drains on spreading fire to other areas is described in Section A.1.1.1 of Enclosure 2 to NL-04-2326 as follows:

> "There are several floor drains on the Pump Deck around the Unit 1 and Unit 2 Service Water pumps. Waste fluids are drained to a 10 cm (4 inch) header, which is also connected to floor drains in a trench system in Fire Zones 72B and 72E. The drain header carries waste fluid to a common sump in the center of the SWIS in the Strainer Pit. Because the header is located below the drains on the Pump Deck and Fire Zone 72B, combustible fluids would not travel between Fire Area 72A and Fire Areas 72B and Fire Area 72E. In addition, because there is no requirement for waste fluid drain lines to be equipped with flame arrestors [NFPA 30, 2000; NFPA 54, 2002; NFPA 69, 2002, and UL 525, 1994], it may be inferred that such drain lines are not a credible fire spread mechanism."

The Fire Brigade Leader would assess a fire at the SWIS. Foam would be used as required to suppress a fire involving an oil spill. Foam is readily available to the Fire Brigade. Fifteen gallons of AFFF foam are available in the Fire Brigade Van and 10 gallons are available on the Fire Tanker Truck. An additional 100 gallons is available from the Storeroom. A foam eductor is available from the Fire Brigade Van or the Fire Tanker Truck. If foam was used, the automatic suppression system would be isolated and any hose streams would be discontinued to allow a blanket of foam to form over the oil.

NRC Question 15

From Attachment B of the exemption request, it appears that the CFAST and HEATING computer fire models were used to determine that in the event of a fire in Fire Area 72, cables, cable trays and motor terminal boxes for service water pumps would not be damaged. The staff requests the detailed analysis, including assumptions and results of the fire modeling for further staff review. In addition, provide the input files used in the CFAST and HEATING fire simulation for all fire scenarios for Fire Area 72.

SNC Response:

Enclosure 2 to NL-04-2326 provides documentation of the CFAST and HEATING computer fire models. This documentation includes input assumptions, derivation of input data, input data, output data, and sensitivity/safety margin estimates. All CFAST and HEATING input files are attached in Sections A.7 and A.8, respectively. HEATING input files are abridged in the report due to the large number of data points associated with the exposure profiles.

NRC Question 16

The page B-8 and B-9, paragraph under, "Initial Assessment," states "The critical failure mode was found to be damage to the power and control cables, either in the cable trays or in the motor terminal boxes."

For each fire scenario, provide a description of the target parameters (e.g., thermoplastic or thermoset cables including wiring that is part of the motor terminal boxes), target damage threshold values, and bases for the damage threshold values. For the fire damage threshold values related to cables, what is the impact when reassessing the scenarios based on a damage threshold of 400^{0}F for thermoplastic cables or 625^{0}F for thermoset cables, as applicable. (See RAI #2 above for reference.) Provide cable construction information (i.e., insulation and jacket material, such as XLPE/PVC) for cables installed in cable trays, motor terminal boxes or exposed (such as air drops) in Fire Area 72, including vendor and/or manufacturer.

The fifth bullet on page B-9 states that "...all cables in the SWIS are IEEE-383." Please clarify that this statement is applicable to all cables (e.g., power, control, signal) of interest in the SWIS including any cable that could act as an intervening combustible, and cable/wiring that are part of the motor terminal boxes.

SNC Response:

The following table contains a listing of the vendor, jacket material, and insulation material of the cables in the SWIS:

<u>Vendor</u>	<u>Jacket Material</u>	<u>Insulation Material</u>
Okonite	Hypalon	EPR
Okonite	Kerite FP	Kerite FP
Okonite	Kerite FP	Kerite HT
Okonite	Neoprene	EPR
Boston Insul.	Neoprene	EPR
Beldon	PVC	PVC

Power and control cables have jacket and insulation materials that are IEEE-383 qualified and utilize thermoset materials. Eight PVC cables were identified that are being used as instrument cables for cameras; portions of these cables will be removed to meet the fire model analysis.

The following descriptions of target parameters, target damage threshold values, and bases for the damage threshold values are applicable to all three fire scenarios:

<u>Thermoset versus Thermoplastic</u>

See response to NRC Question 2 for the discussion on the 625^{0}F damage threshold of thermoset cables.

The PVC cabling will be removed from the trays along the south wall to eliminate the consideration of a fire in the cable trays, ignited from a Service Water Pump fire. The cabling will be removed along the entire run of the pump deck. The PVC jacketed cabling in the Northeast corner has no impact on the results of the analysis (See Enclosure 2 to NL-04-2326).

Motor Terminal Boxes

Based on site work history, the ten service water pump motors are spliced to the field cables using Raychem Kit NMCK (Nuclear Motor Connection Kit) 8-1L. The cables are spliced using compression terminals joined using a bolt or machine screw, a hex nut, and washer as seen in the attached drawing. Both Okonite tape and Raychem Kit NMCK8-1L have been used for splice coverings.

The Raychem NMCK8-1L splice kit is used to connect 5 – 8 kV in-line feeder and motor lead cables between 2/0 and 250 kcmil. The splice involves a minimum of two layers of protective sheathing that is heat shrunk over the connection and a specified distance beyond the connection over the cable insulation. The sheathing material is IEEE-383 qualified and is composed of cross-linked polyolefin, a thermoset polymer material [Beyler et al., 2002].

Circuit failure modes are discussed by Salley [2004] and include the following:

- Conductor-to-conductor short circuits
- Conductor-to-external ground short circuits
- Loss of conductor insulation resistance
- Loss of conductor continuity

Except for loss of conductor continuity, each circuit failure mode would require the loss of or substantial damage to the cable insulation or, in the case of a splice, loss of or damage to the protective sheathing or tape. Loss of conductor continuity would be expected from mechanical damage or if the conductor were heated such that the local stresses exceeded its yield strength. In the case of a splice, loss of conductor continuity could occur if the metals involved began to melt or if the splice was under load and the stress exceeded the yield strength of the connection mechanism (i.e., a crimp or compression fit) or the metal.

Current NRC guidelines indicate that the maximum acceptable temperature for cables using thermoset insulation is 625°F [NRC, 2004]. This temperature is applicable to any cable that uses thermoset insulation, regardless of the insulation thickness. Given this, it may be inferred that the critical temperature for a splice connection would also be 625°F, provided that a thermoset sheathing/wrapping is used and that there is no loss of conductor continuity. This inference follows because the sheathing/wrapping protecting a splice performs the same function as the cable insulation, assuming it is installed per manufacturers instructions, has the same minimum damage criteria as cable insulation, and the thickness of which relative to the field/terminal cables is not material. Such a splice would thus not be more susceptible to circuit failure when heated as compared to an insulated thermoset cable with regard to damage or loss of insulation/sheathing/wrapping.

A threshold temperature of 625°F is justified for use with the Service Water Intake Structure (SWIS) pump motor junction box connections because of the following:

- The splices are mechanically protected within a terminal box.
- The connections are not stressed within the box (they do not carry gravity loads). Given this, it may be concluded that heating the splice connections would not cause the cable, compression terminals crimped to the cable, or the hex nut connections to fail unless the temperatures approached the melting point for one or more of the metals involved (copper, steel, aluminum–confirm with site).
- The sheathing is IEEE qualified and utilizes a thermoset material.
- The increased separation between conductors within the junction box as compared to the cable reduces the potential for conductor-to-conductor short circuits and reduces the potential for loss of insulation resistance to adversely impact the circuit.

Loss of conductor continuity would be prevented by limiting the temperature of the splice system such that the metals involved are well below their melting temperature. The minimum melting temperature for the metal involved is 2,010°F for copper, significantly greater than 625°F. The junction box housing provides protection from external sources of mechanic damage. Because the sheathing is thermoset material that meets the IEEE-383 flammability criteria, short circuits and damage to the sheathing would be prevented by maintaining the system temperature below 625°F, the NRC temperature limit for thermoset cable insulation [NRC, 2004].

In addition, the latest guidance given in Attachment 6 to Appendix F of the Fire Protection Significance Determination Process states:

> "For major components such as motors, valves, etc., the fire vulnerability will be assumed to be limited by the vulnerability of the required power, control, and or instrument cables supporting the component."

NRC Question 17

Where applicable in Fire Area 72, discuss how thermoset and thermoplastic cables located in the same electrical raceway were addressed with respect to fire propagation and fire damage to target cables.

SNC Response:

All cables in the cable trays in Fire Area 72 are thermoset. Therefore the issue of thermoplastic interacting with thermoset cables is not an issue. Fire propagation along cable trays was not an issue in any of the scenarios, since the closest cable trays were the targets.

NRC Question 18

The page B–12, "Fire Modeling Input Assumptions," eighth bullet states that doors and openings were assumed shut. Provide a summary basis for this assumption and demonstrate that it bounds the open door assumption (i.e., open door when fire brigade or operators enter the SWIS or its zones). Describe how mechanical ventilation systems were addressed in the fire modeling and provide any ventilation flow rates provided by mechanical equipment.

SNC Response:

The doors form part of the fire area boundary and are normally closed. Except for the Unit 1 service water pump lubricant fires, the scenarios were not ventilation limited. In this case, opening doors would allow combustion products to escape and result in a somewhat lower some layer temperature prediction. The temperatures for the Unit 1 service water pump lubricant fires reached a steady state condition prior to the development of ventilation limited conditions thus it was not considered a significant parameter.

This assumption was removed and ventilation effects were quantified. The results are summarized in Enclosure 2 to NL-04-2326. It was determined during a sensitivity assessment that opening one or two doors has an insignificant effect on the smoke layer temperature and has a slight effect on the steady state smoke layer position. It was found that opening doors would not change the results or conclusions.

A mechanical exhaust system is provided above the service water pumps for removing excess heat during motor operation. There are three exhaust fans per Unit, each fan is capable of exhausting 4.7 m^3/s (10,000 cfm). The fans are not designed to exhaust combustion products and would likely fail during a fire due to the high temperatures. Nevertheless, a sensitivity analysis was performed where the Unit 1 or Unit 2 exhaust fans actuate and the Unit 1 and Unit 2 exhaust fans actuate. It was found that for some scenarios, the fans have sufficient capacity to maintain the smoke layer above certain targets. This would prevent these targets from being immersed in the smoke layer. However, they would be exposed to a flame radiation boundary condition for the duration of the fire. The target response under these circumstances was computed, it was found that for a fire in a Unit 1 service water pump, adjacent pump motor junction box targets could be heated to a temperature greater than 330°C (625°F). As a result, these targets were assumed to fail despite the MEFS showing that they would not. All other targets remained below the critical surface temperature of 330°C (625°F). The details and results of the mechanical ventilation sensitivity evaluation are contained in Enclosure 2 to NL-04-2326.

NRC Question 19

The page B-11, "Fire Modeling Input Assumptions," ninth bullet states that the transient combustibles consisted of an equal mix of cellulose based and plastic based material. Provide the basis for why flammable and/or combustible liquids or flammable gases were not assumed in light of the fact that at power maintenance activities have occurred in the SWIS (see RAI #16 above). Provide the basis for the transient fire 332 Btu/s heat release rate for 600 seconds as done in scenario 1.

SNC Response:

The heat release rate of a trash bag fire containing a mix of cellulose and plastic, typical refuse material in industrial occupancies such as the SWIS, is a function of several variables, including the contents, the packing density, and the volume of the bag. The development of the scenario is discussed in detail in Enclosure 2 to NL-04-2326. Trash bag fire tests show that the peak heat release rate may vary from less than 100 kW (95 Btu/s) to nearly 350 kW (332 Btu/s). Figure 1 shows that heat release rate profiles for three trash bag fire tests where the packing density ranged from 30 kg/m^3 (1.9 lb/ft^3) to 100 kg/m^3 (6.2 lb/ft^3) and the number of trash bags ranged from one to three [Lee, 1985; Babrauskas, 2002].

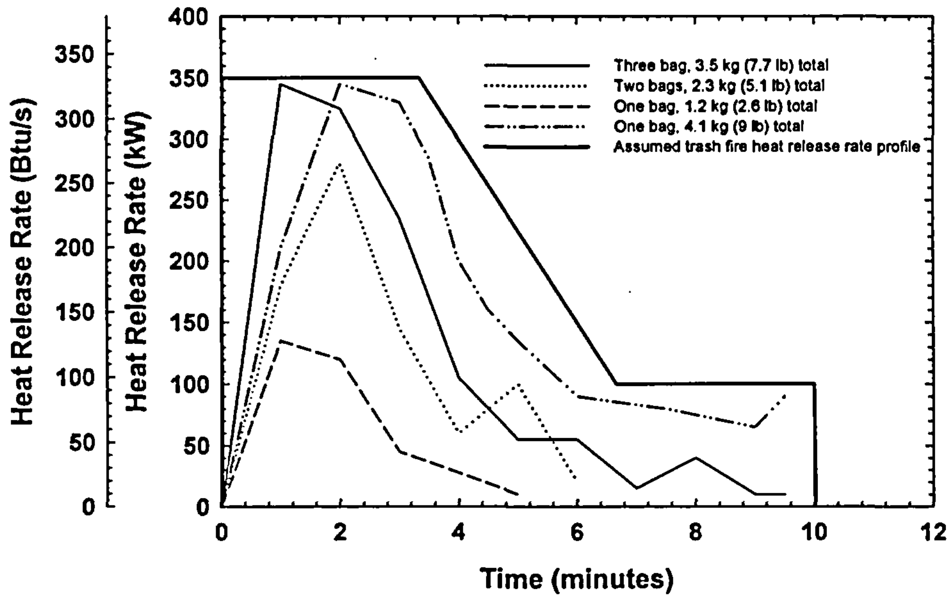


Figure 1: Trash (Cellulose and Plastic Mix) Heat Release Rate Profiles [Babrauskas, 2002]

Based on a review of available data, the heat release rates shown in Figure 1 are conservative yet realistic. As such, an assumed heat release rate profile for Scenario 1 was developed using the data shown in Figure 1. The assumed energy release rate profile thus consists of three segments:

- 350 kW (332 Btu/s) for the first 200 seconds.
- A linear decrease from 350 kW (332 Btu/s) to 100 kW (95 Btu/s) between 200 seconds and 400 seconds after ignition (average heat release rate of 225 kW [213 Btu/s] for interval).
- 100 kW (95 Btu/s) between 400 seconds and 600 seconds after ignition.

Note that this is considerably larger than the 50th and 95th percentile transient combustible fuel packages specified in the most recent revision of the Fire Protection Significance Determination Process (SDP), namely 70 kW (66 Btu/s) and 200 kW (190 Btu/s), respectively.

In order to address the potential for oil-soaked rags that may be contained within the trash in the northeast corner, a sensitivity analysis was performed on the fuel package contents. The sensitivity evaluation is summarized in Enclosure 2 to NL-04-2326 . The basic assumption is that oil-soaked rags would not significantly impact the duration of the fire (i.e., low mass relative to the overall fuel package), but could result in an increase in the heat release rate growth rate and the peak heat release rate. It was concluded that a peak heat release rate more than five times larger than that assumed is required to cause the target surface temperature to exceed 625°F, the critical value.

NRC Question 20

The page B-12 and B-13 "Fire Modeling Results" for Unit 1 and Unit 2 Service Water pump fire scenario discusses service water pump oil fires and loss of pumps by a single pump fire. Page B-13 states that, "CFAST was used to determine the smoke temperature in the SWIS and HEATING was used to calculate the surface temperature of the Service Water pump motor junction box targets and the east wall cable tray target." Describe the results for a pump fire with loss of pumps and effects of fire to nearby 'A' or 'B' train cables as applicable (e.g., Unit 2, Train A Service Water pump fire and effects to adjacent service water pumps and to nearby Train B cable trays). Include in the description any effects from intervening combustibles, ceiling height, fire plume, hot gas layer, radiant heat flux from flames and from hot gas layer, and beam pockets.

SNC Response:

See Enclosure 2 to NL-04-2326, sections A.1, A.2, A.3, A.4, and A.5 which describe target sets, analysis, and fire modeling results.

NRC Question 21

The page B-13, scenario 3 assumes a fire involving 8 gallons of lube oil versus scenario 2 which assumes 22.5 gallons of lube oil. Provide the basis for the lower value of lube oil in scenario 3.

SNC Response:

The Unit 1 and Unit 2 service water pumps are different models. Scenario 2 involves the volume of lubricant contained in the single largest oil reservoir associated with any one of the five Unit 1 Service water pumps located on the east side of the pump deck. Per the Unit #1 Lubrication Manual General Revision #38 (October 19, 2000), the largest single reservoir contains 90 quarts (22.5 gallons) of Regal R&O 68 for the pump thrust bearing.

Scenario 3 involves the volume of lubricant contained in the single largest oil reservoir associated with any one of the five Unit 2 Service water pumps located on the west side of the pump deck. Per the Unit #2 Lubrication Manual General Revision #34 (October 19, 2000), the largest single reservoir contains 8 gallons of Regal R&O 68 for the pump motor upper thrust bearing.

NRC Question 22

Drawing D-171331 shows beam pockets formed by concrete beams. Describe how the fire modeling accounted for these pockets (i.e., potential hot gas layer forming initially in a single beam pocket, etc.), where applicable.

SNC Response:

The impact of beam pockets is summarized in section A.3.2.1 of Enclosure 2 to NL-04-2326. The following excerpt applies:

"As noted in Section A.1.1.1, the ceiling of the SWIS structure is subdivided by 1 m (3 ft) thick beams into a series of cells or beam pockets. Beam pockets would likely interrupt the ceiling jet flow and could impact the actuation time of detection devices located at the ceiling or the exposure temperature to targets within the beam pocket or the ceiling itself. The beam pockets are not expected to have a significant influence on the overall smoke layer formation because there is a sufficient volume of smoke generated to completely fill the beam pockets and descend to lower elevations. Since there are no targets within the beam pockets and detection is not credited for the scenario evaluated, the presence of beam pockets would not change the results or conclusions applicable to this scenario.

As part of the defense-in-depth, potential for sprinkler system is evaluated for each scenario though actuation is not directly credited with mitigating the effects of a fire scenario. Beam pockets in the SWIS would likely influence the actuation of the sprinkler and detection systems [Koslowsi et al., 1992]. The effect may be an increase or decrease in the actuation time relative to a flat ceiling, depending on the location of the sprinkler in the beam pocket and the fire centerline. This effect is not directly modeled in this section; however, sprinkler actuation under a range of temperature and velocity conditions that would bracket the conditions in the beam pockets are considered. These conditions range from a nearly stagnant smoke layer to a typical ceiling jet."

NRC Question 23

Regulatory Guide 1.174, Section 2 discusses five key principles that a change is expected to meet. Describe how each key principle is met with the proposed change.

SNC Response:

Following are the five key principles from Revision 1 of Regulatory Guide 1.174 and how they are met with the proposed change:

Principle 1. The proposed change meets the current regulations unless it is explicitly related to a requested exemption or rule change, i.e., a "specific exemption" under 10 CFR 50.12 or a "petition for rulemaking" under 10 CFR 2.802.

The proposed change is associated with a specific exemption from certain requirements in 10 CFR 50, Appendix R for Fire Area 72. The proposed change is submitted in accordance with the requirements of 10 CFR 50.12. Therefore, the proposed change is in accordance with this key principle.

Principle 2. The proposed change is consistent with the defense-in-depth philosophy.

The proposed change is consistent with the defense-in-depth philosophy. See the response to NRC Question 24 for details on how the proposed change is consistent with the defense-in-depth philosophy.

Principle 3. The proposed change maintains sufficient safety margins.

The proposed change maintains sufficient safety margins. See the response to NRC Question 25 for details on how the proposed change maintains sufficient safety margins.

Principle 4. When proposed changes result in an increase in core damage frequency or risk, the increases should be small and consistent with the intent of the Commission's Safety Goal Policy Statement.

The results of the risk assessment show a conservatively estimated risk increase to be approximately 6.5E-07/yr. per unit. This places the proposed change in Region III of the Regulatory Guide 1.174 acceptance criteria for core damage frequency (CDF). Region III allows the cumulative total plant risk to be greater than 1.0E-04/yr. The total plant CDF from internal events for Unit 1 and 2 is 3.86E-05/yr. and 5.81E-05/yr., respectively. A comparison of the Farley Fire IPEEE results with the internal events PRA results that were applicable at that time shows that the Unit 1 Fire CDF was approximately 20% higher than the corresponding Unit 1 internal events CDF. This would result in an estimated total plant risk of less than 8.5E-05/yr.

The Unit 2 Fire CDF was approximately 10% less than the corresponding Unit 2 internal events CDF. This would result in an estimated total plant risk for Unit 2 of 1.1E-04/yr. Given these factors, it can be concluded that the cumulative plant risk for Unit 1 and 2 would meet the Regulatory Guide 1.174 criteria. Also, refer to responses to NRC Questions 3, 6, 7, and 8 for additional information on core damage frequency impact of the proposed change.

Therefore, the proposed change in core damage frequency is small and consistent with the Commission's Safety Goal policy statement.

Principle 5. The impact of the proposed change should be monitored using performance measurement strategies.

Monitoring of key parameters is an integral part of a risk-informed, performance-based approach. Since the SWIS fire scenario is a limited, focused application, the monitoring of key parameters is focused on two primary areas:

1) Ensuring availability of the Service Water System (SWS).

<u>Service Water System</u>

Since the Service Water system is a safety-related system that is relied upon in response to design basis accidents, its operability is rigorously controlled by the Plant Technical Specifications. Several major Technical Specifications and Technical Requirements ensure that the Service Water system is available. These include:

- Service Water System

  In order to support safety-related purposes, Technical Specifications require that two Service Water trains be operable in Modes 1 through 4. An operable Service Water train is defined in the Technical Specification Bases as two operable pumps in the train, with the associated piping, valves, and instrumentation and controls operable.

  If two Service Water Trains are not operable in Modes 1 through 4, the unit is required to be in Mode 3 within 6 hours and within Mode 5 within 36 hours.

Technical Specifications provides for the required redundancy to ensure that the system functions to remove post accident heat loads, assuming the worst case single active failure occurs concurrent with a loss of offsite power.

The requirements for post-fire safe shutdown are less restrictive than those required for accident mitigation. The operability of the Service Water system as governed by the Technical Specifications fully envelopes the post-fire safe shutdown needs.

The risk-informed, performance-based assessments have an initial condition of two operable Service Water trains with two operable pumps per train. This includes the potential use of the swing pump (C pump) when one of the train dedicated pumps is out of service. Ensuring two operable Service Water trains (with two operable pumps per train) ensures that the initial conditions assumed in the fire modeling and risk assessment are valid.

Therefore, the monitoring provided associated with the Service Water system for its design basis accident function is adequate and appropriate for use of the system in a risk-informed, performance-based program. The Service Water system is monitored under the Farley Maintenance Rule program. The availability and reliability of the system, as maintained by the program, supports the risk-informed, performance-based fire protection application for the SWIS.

An additional item that requires monitoring to maintain consistency with the risk assessment is the selection of the "On-Service" train when the C Service Water pump is in operation. Train A should not be selected as the "On-Service" train if Service Water Pump A is not operating or is otherwise unavailable. Train B should not be selected if Service Water Pump E is not operating or is otherwise unavailable. If Service Water Pumps A and E are both operating, then either train can selected as the "On-Service" train.

- Ultimate Heat Sink

Technical Specifications ensure the availability of the Service Water Pond to support Service Water system operation. The Service Water Pond level requirements and water temperature requirements fully bound the 10 CFR 50, Appendix R post-fire safe shutdown scenario and provide adequate assurance of the ultimate heat sink availability.

- Ultimate Heat Sink (UHS) Support Structures

Technical requirements ensure the integrity of the Service Water Pond. This technical requirement is more than adequate to support post-fire safe shutdown requirements, which require substantially less than a 30 day requirement of water to proceed to cold shutdown. Verifying that the pond is intact is consistent with the requirements of the pond for post-fire safe shutdown. Therefore, the requirements of the technical requirement fully bound the 10 CFR 50, Appendix R post-fire safe shutdown scenario and provide adequate assurance of the ultimate heat sink availability.

2) Ensuring conditions in the SWIS are consistent with the risk-informed, performance-based approach.

SWIS Conditions and Equipment

Conditions and parameters associated with the SWIS that are not related directly to the Service Water system, but warrant additional consideration include:

- Combustible Control within the SWIS

  Processes and procedures are in place at Farley to address housekeeping and control of combustible loading throughout the plant. This includes housekeeping and combustible loading control in the SWIS.

  Plant procedures define the responsibilities for maintaining the plant in a clean and orderly condition. The procedure also delineates control measures which must be followed in various plant areas in order to maintain their cleanliness. These procedures include responsibilities for periodic inspections by the plant fire marshal of all plant areas with an emphasis on fire prevention and protection.

  Procedures also provide guidance that is used at management discretion in order to provide a systematic methodology for housekeeping inspections. The guidance includes cleanliness inspections for general areas and assignments of responsibilities to different plant organizations. This includes responsibilities for the SWIS.

  Procedures also provide guidance for bringing combustibles into a fire area for any plant activity. The procedures also provides guidance for determining the amount and type of fire extinguishing equipment in the event of temporary increases in potential fire loading, and provides guidance for the amount of combustibles that may be taken into a particular area without having additional suppression means for additional fire watches.

  Processes and procedures are in place to control conditions that support the risk-informed, performance-based assessment. However, additional specific transient combustible controls will be implemented to restrict transient combustibles from being stored/located in the northeast corner and in the vicinity of the Service Water pumps. This will provide additional assurance that the conditions of the risk-informed, performance based evaluation are met and that defense-in-depth is maintained in the area.

- Fire Detection Suppression and Detection Equipment

  The SWIS is provided with area-wide detection and localized fire suppression pre-action sprinkler systems. In addition, localized carbon dioxide suppression systems are provided in the switchgear and transfer switch panels. It is noted that, in the detailed fire modeling and risk assessments performed in support of the exemption request, no specific credit was taken for detection of fire, fire suppression system extinguishing/controlling the fire, or manual fire fighting to extinguish the fire. Therefore, the availability of detection and suppression system was not specifically relied upon in the calculation of core damage frequency due to a fire in the SWIS.

  Although not specifically relied upon in the risk-informed, performance-based assessment, the operability of the SWIS systems have been and will continue to be administratively controlled to ensure adequate defense-in-depth and safety margins will be maintained. The Farley Final Safety Analysis Report (FSAR) provides operability and surveillance requirements for fire protection systems, including those provided for the SWIS. This includes:

- Operability of the detection systems within the SWIS.
- Operability of the preaction sprinkler systems (pump deck, strainer pit, and northeast corner and in other areas where previous credit was taken for raceway fire barrier protection).
- Operability of the local carbon dioxide systems for the switchgear and cabinets.
- Operability of the SWIS fire hose stations.

- Floor Curbs

  The curbs in the SWIS and the slope of the floor help to confine a lubricant spill and limit fire damage to adjacent pumps if a swing pump lubricant fire were to occur. In addition, a new curb is recommended as a plant modification as a result of this risk-informed, performance-based assessment. Floor curbs will be added to a formal routine inspection program to ensure that they are present and undamaged.

- Lubricant Type and Quantity

  The type and quantity of lubricant used in the Service Water pump motors is used in the fire modeling assessment. The quantity of lubricant used in the fire scenarios is extremely conservative, as the entire contents were assumed to be emptied onto the pump deck and ignited.

  The quantity and type of lubricant will be included in the fire protection design review process to ensure that future changes do not invalidate the results of the risk-informed, performance-based assessment.

- Passive Fire Barriers

  Key passive fire barriers within the SWIS are maintained as fire area boundaries. Therefore, the surveillance program provides the operability requirements and compensatory measures to ensure that the conditions of the risk-informed, performance-based assessment remain valid. As part of the risk-informed, performance-based assessment, upgrades to barriers within the SWIS were identified to enhance fire safety. The scope of the barrier surveillance program will be enhanced to ensure that the conditions of the risk-informed, performance-based assessment are maintained.

NRC Question 24

Pages B-16 and B-17 discuss Defense-in-Depth/Safety Margins. There are seven bullets listed on Page B-16 that are taken from Regulatory Guide 1.174 to determine if consistency with defense-in-depth is maintained. The bottom half of Page B-16 provides a very brief discussion on each of the seven bullets. However, the discussion for each item is very brief or does not provide any basis for a reviewer to assess whether each item has been fulfilled. For each item, provide a qualitative or traditional engineering argument or by using PRA results contained in the accident sequences or cutsets, as appropriate.

SNC Response:

Regulatory Guide 1.174 identifies several factors to be considered when evaluating defense-in-depth in general. Consistency with the defense-in-depth philosophy is maintained if:

- A reasonable balance is preserved among prevention of core damage, prevention of containment failure, and consequence mitigation.

  The proposed change ensures that a reasonable balance is preserved among prevention of core damage, prevention of containment failure, and consequence mitigation. The proposed changes have no effect on the ability of the Service Water system to perform its design basis accident mitigation function. The proposed change also has no effect on containment failure, so the effect of the change is neutral and maintains an appropriate balance. The proposed change has no effect on consequence mitigation.

  The only scenario associated with a change is a fire scenario in the SWIS. Changes in passive features have been counterbalanced by addition of passive features (e.g., curbs, sealed walls) in areas where potential risk reductions could be achieved. The ability to suppress fires with the installed suppression systems, although specifically not credited in the risk assessment of the proposed change, remains unaffected by the proposed change. Administrative controls implemented with the change help to minimize the likelihood of a significant fire in the SWIS, thus providing an enhanced level of safety and ensuring balance among the different elements of defense-in-depth.

  The proposed change has only a small calculated impact on core damage frequency and large early release frequency. The change does not affect containment integrity. The change neither degrades core damage prevention at the expense of containment integrity, nor degrades containment integrity at the expense of core damage prevention. The balance between preventing core damage and preventing containment failure is the same. Consequence mitigation remains unaffected by the proposed changes. Furthermore, no new accident or transient is introduced with the requested change, and the likelihood of an accident or transient is not impacted.

- Over-reliance on programmatic activities to compensate for weaknesses in plant design is avoided.

  The Service Water system will still function in the same manner with the same reliability. Design enhancements will help minimize the potential for a significant fire and potential spread to redundant trains. Administrative controls to restrict combustibles in critical areas will help strengthen fire prevention in the area. However, this is not considered "over-reliance," rather one aspect of a multi-faceted approach to fire safety in the area.

- System redundancy, independence, and diversity are preserved commensurate with the expected frequency, consequences of challenges to the system, and uncertainties (e.g., no risk outliers).

  There is no impact on the redundancy, independence, or diversity of the Service Water system or on the ability of the plant to respond to events with diverse systems. The Service Water system is a diverse and redundant system and will remain so.

- Defenses against potential common-cause failures are preserved, and the potential for the introduction of new common-cause failure mechanisms is assessed.

  Potential against common-cause failures are preserved. The proposed changes do not introduce any new common-cause failures or change the operating environment of the Service Water system in the SWIS. In addition, backup systems are not impacted by this change and no new common-cause links between the primary and backup systems are introduced. The likelihood and consequences of significant fires in critical areas of the SWIS are not increased. Therefore, the potential for a single fire resulting in unacceptable damage (common-cause failure) is unchanged. No modifications or operational concerns associated with the proposed change will introduce or increase the likelihood of a common-cause failure of the service water system.

- Independence of barriers is not degraded.

  The independence of barriers associated with the proposed change is not degraded. The barriers protecting the public and the independence of these barriers are maintained. The proposed change in no way provides a mechanism that degrades the independence of the barriers; fuel cladding, reactor coolant system, and containment. The integrity of the fuel cladding is not challenged by this change. Likewise, the reactor coolant system boundary is unaffected by this change. Due to the remote location and design of the SWIS, the proposed change does not impact the containment boundary. Therefore, the three primary barriers associated with nuclear safety are unaffected by the change. In addition, the independence of these key barriers is completely unaffected by the change.

- Defenses against human errors are preserved.

  The proposed change provides a technical, defensible basis as to why the existing and proposed plant configuration is safe and will not allow a significant fire to impair post-fire safe shutdown capability. The changes and the post-fire safe shutdown strategy (in general) for a fire in the SWIS have minimal reliance on human action. The inherent redundancy of the Service Water system, physical separation of redundant components within the SWIS, and passive and active fire protection systems help to minimize reliance on human intervention to prevent or mitigate the effects of fire. New administrative controls are being added to provide additional assurance that a significant fire will not occur in the SWIS.

- The intent of the General Design Criteria in Appendix A to 10 CFR 50 is maintained.

  The General Design Criteria (GDC) in Appendix A to 10 CFR 50 include a number of topics, including overall requirements, protection by multiple fission product barriers, protection and reactivity control systems, fluid systems, reactor containment, and fuel and reactivity control. The proposed changed maintains the intent of the General Design Criteria. Of particular interest is criterion 3 of Appendix A to 10 CFR 50:

  "Fire protection. Structures, systems, and components important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions. Noncombustible and heat resistant materials shall be used wherever practical throughout the unit, particularly in locations such as the containment and control room. Fire detection and fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems, and components important to safety. Firefighting systems shall be designed to assure that their rupture or inadvertent operation does not significantly impair the safety capability of these structures, systems, and components."

The proposed change, as discussed in detail in the exemption request, meets the intent of GDC 3 and provides a level of safety consistent with the original licensing basis for the SWIS.

Therefore, as discussed above, the factors related to defense-in-depth that are outlined in Regulatory Guide 1.174 are met and are considered acceptable. In addition to the factors discussed above, a table outlining the elements of fire protection defense-in-depth (preventing fires from starting, detecting fires quickly and suppressing those that occur, thereby limiting damage, and providing protection for systems and structures so that safe shutdown can be achieved) is provided for the proposed changes in the SWIS. The table outlines and strengthens the broad array of fire protection elements and demonstrates a reasonable balance and independence, consistent with the defense-in-depth principles outlined in Regulatory Guide 1.174.

Fire Area 72 - SWIS – Defense-in-Depth Summary

Element	Farley SWIS CLB	Changes	Net Effect
Preventing fires from starting.	Existing plant housekeeping, basic plant electrical design.	Enhanced transient combustible controls in the SWIS NE corner and vicinity of pumps	Element of defense-in-depth is strengthened.
Detecting fires quickly and suppressing those that occur, thereby limiting damage.	Detection throughout the SWIS, preaction sprinkler systems on the pump deck, strainer pit, and NE corner, preaction spray for the SW pumps, local CO_2 for the switchgear and disconnect switches, hose stations and hydrants.	No physical or programmatic changes to active fire detection and suppression systems (although no credit is taken for detection and suppression in RI-PB analysis)	No physical changes in the defense-in-depth element. Success is demonstrated in RI-PB analysis without credit for detection and suppression.
Providing protection for systems and structures so that safe shutdown can be achieved.	Physical separation of redundant trains of safe shutdown equipment/cables.	The population of equipment requiring protection has been reduced due to analysis (i.e., single SW pump, MOV circuit analysis) and modifications (U2 lube & cooling).	Element of defense-in-depth is strengthened.
	Kaowool was used in limited application in NE corner, strainer pit, and SW pump power cables.	Strainer pit Kaowool not necessary (cables failures don't adversely affect safe shutdown), other Kaowool not credited (damage to redundant equipment is assessed using fire modeling/risk analysis without credit for Kaowool).	Element of defense-in-depth is weakened.
	Non-rated fire zone boundaries, when combined with other elements, prevent spread of fire between zones and damage to redundant equipment/cables.	Fire barriers between pump deck and switchgear rooms and between disconnect switch rooms will be updated to 3-hr. rated barriers.	Element of defense-in-depth is strengthened.
	Curbs and radiant shields on the pump deck limit oil spread and radiant exposure.	Curb will be installed on Unit 1 side of pump deck to limit potential exposure to Train A raceways along east wall.	Element of defense-in-depth is strengthened.

NRC Question 25

Pages B-16 and B-17 discuss Defense-in-Depth/Safety Margins. There are two bullets listed on Page B-17 that are taken from Regulatory Guide 1.174 to determine if sufficient safety margins are maintained. Regulatory Guide 1.174, section 2.2.1.2 provides a set of acceptable guidelines to ensure sufficient safety margins:

> "Codes and standards or their alternatives approved for use by the NRC are met.
>
> Safety analysis acceptance criteria in the LB (e.g., FSAR, supporting analyses) are met, or proposed revisions provide sufficient margin to account for analysis and data uncertainty."

The second bullet on page B-17 addresses the safety margins guidance for the proposed change or revision by accounting for analysis and data uncertainty. The licensee compares MEFS and LFS to account for analysis and data uncertainty on Pages B-12 through B-14.

Scenario 1 appears to report the safety margin in terms of heat release rate (HRR) (and time) and mass of combustibles. Scenarios 2 and 3 appear to report safety margin in terms of mass (or volume) of combustibles only. Please clarify why it is appropriate to consider only the mass (or volume) of combustibles for safety margins in Scenarios 2 and 3 where the lube oil is pooled within a bermed or confined area (include the basis for why HRR was not considered).

For each of the three scenarios, discuss acceptability of the safety margins and their values, taking into account uncertainties with fire modeling and with fire input data (parameters). Provide a discussion on the acceptability of the margins between the MEFS and LFS considering the potential effect and severity on the plant if a LFS occurred.

SNC Response:

Uncertainty in the analysis is addressed in three distinct ways:

- The safety margin
- The LFS
- Sensitivity of the results to input assumptions

The safety margin is used in the context of this analysis as the degree to which the models/calculations used bound the uncertainty in the input parameters. A safety margin greater than one indicates that the uncertainty is bound. The safety margin for parameters associated with each scenario considered in the SWIS is summarized in the Enclosure 2 to NL-04-2326. A safety margin of one or greater was calculated for all parameters except for the limiting oxygen index (LOI). Assuming a LOI less than ten percent results in a safety margin of 0.97 (a temperature increase of 4°C (7°F)). Data is provided that indicates an LOI less than ten percent is not possible for the temperatures predicted and is therefore not a credible safety margin.

The LFS is determined for each scenario. The LFS is determined by increasing one or more parameters that characterize the fire used for the MEFS until a failure condition is attained. The most obvious choice for the LFS parameter is the heat release rate, but this is not always the most appropriate. In the case of a plume exposing a target in the NE corner, the LFS based only on the heat release rate increase was five times greater than the MEFS heat release rate. However, if an increased combustible mass (i.e., burning duration) is included, a combined smoke layer-plume immersion scenario results. In this case, the LFS heat release rate is only four times greater than the MEFS heat release rate; however a fuel package with five times the assumed mass for the MEFS is required. (See Enclosure 2 to NL-04-2326 for additional details).

A confined pool fire is another example where increasing the heat release rate alone may not be the best choice of LFS parameters. In the case of the service water pump lubricant spill fires, the LFS was determined by increasing the flame emissive power as well as by increasing the heat release rate. It was found that the LFS heat release rate is two-to-four times the MEFS heat release rate. However, it was determined that the LFS flame emissive power for adjacent pumps would be about 20% greater, a much smaller difference than the heat release parameter rate alone would indicate. Such a small LFS margin provided additional basis for assuming these targets fail, as described in Enclosure 2 to NL-04-2326.

A sensitivity analysis is the final component in quantifying the influence of uncertainty. A sensitivity analysis is related to the safety margin, though the goal is not necessarily to demonstrate that the results are bounding but rather that the conclusions would not be altered. The sensitivity is typically conducted on general model assumptions regarding the fuel package, ventilation conditions, or the response of the target (absorptance). In the case of the SWIS, sensitivity was conducted on the natural and forced ventilation conditions, the composition of the Class A fuel package (oily rags), and the absorptance of the targets. It was determined that some adjacent pump motor targets could be heated to the critical temperature if the mechanical ventilation system functioned normally for the duration of the fire. Given this finding, it was concluded that these targets would fail, despite the MEFS results to the contrary. Conclusions regarding other targets were not affected. The details and results of the sensitivity studies are contained in Enclosure 2 to NL-04-2326.

NRC Question 26

The page B-18, Conclusions 2 and 3 are based on a deterministic re-analysis that demonstrates fire damage cannot result in spurious operation of the strainer pit valves (service water header strainer inlet MOVs and swing pump discharge MOVs). (See Page B-7 also). Provide the assumptions and the basis for this conclusion.

SNC Response:

The valves in question on page B-18 of the August 23, 2003 exemption request are those specifically discussed in the December 29, 1986 Safety Evaluation Report (SER) for the exemption for Fire Area 72. The valves in question are the following:

Unit 1 side of the strainer pit

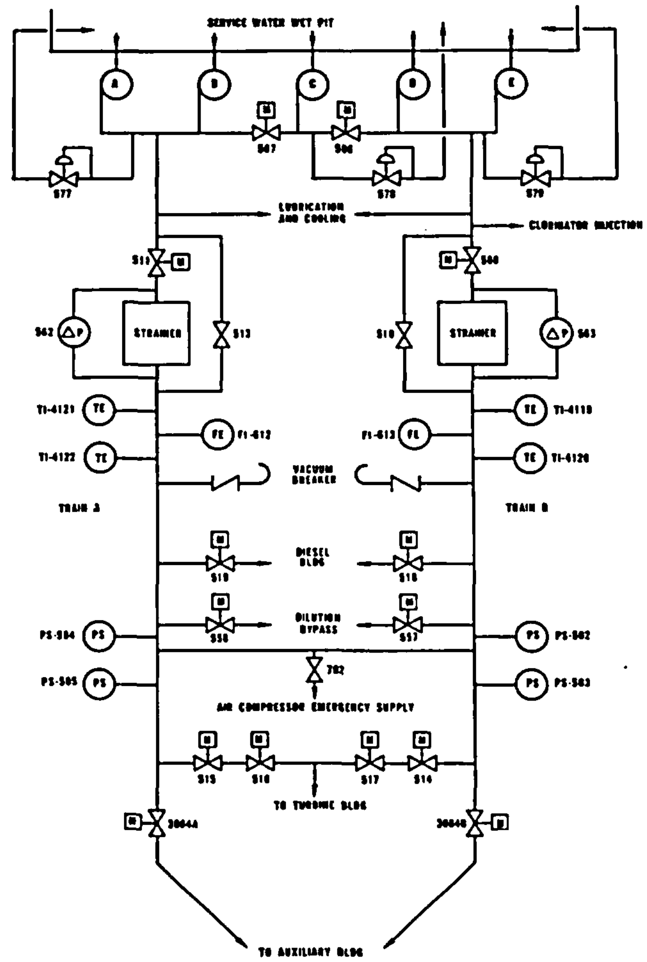
Q1P16V511-A	Service Water Train A Strainer Inlet Valve
Q1P16V508-B	Service Water Train B Strainer Inlet Valve
Q1P16V507-A	Service Water Swing Pump Q1P16M001C-AB Discharge to Train A
Q1P16V506-B	Service Water Swing Pump Q1P16M001C-AB Discharge to Train B

Unit 2 side of the strainer pit

Q2P16V511-A	Service Water Train A Strainer Inlet Valve
Q2P16V508-B	Service Water Train B Strainer Inlet Valve

Q2P16V507-A Service Water Swing Pump Q2P16M001C-AB Discharge to Train A
Q2P16V506-B Service Water Swing Pump Q2P16M001C-AB Discharge to Train B

Following is a simplified diagram of a single unit's Service Water system. The valves labeled "506," "507," "511," and "508" are the valves of concern.



<u>Service Water Strainer Inlet Valves</u>

The strainer inlet valves are normally open motor-operated valves (Q1P16V511-A, Q1P16V508-B, Q2P16V511-A, and Q2P16V508-B) that are desired open to support post-fire safe shutdown. A detailed review of the circuitry located in the strainer pit was performed to determine the failure modes of the cables. The review determined that the cables routed in the strainer pit were power cables to the motor operated valves and control cables to the valve position switches. The failure modes of the cables, if subjected to hot shorts, open circuits, or shorts to ground, could not result in spurious closure of the valves. Therefore, protection of the cables with a raceway fire barrier material is not necessary, although it had previously been provided. The cables and raceways in the strainer pit are listed below:

Valve	Raceway	Cables
Q1P16V511-A	AEN007	1ZAFK-C3P
Q1P16V511-A	AHS127	1ZAFK-C3C
Q1P16V508-B	BHP093	1ZBFL-C3C
Q1P16V508-B	BEN008	1ZBFL-C3P
Q2P16V511-A	AEN251	2ZAFK-L3P
Q2P16V511-A	AHP850	2ZAFK-L3B
Q2P16V508-B	BEN251	2ZBFL-L3P
Q2P16V508-B	BHP328	2ZBFL-L3B

Swing Service Water Pump Discharge Valves

As discussed on page B-7 of the August 23, 2003 exemption request (and discussed in response to NRC Question 1), power to the swing Service Water pump discharge valves is removed during normal operation. Therefore, power is removed to Q2P16V507-A, Q2P16V506-B, Q1P16V507-A, and Q1P16V506-B during normal operation. With power removed to the valves, spurious operation of the valves is not credible, since 3-phase ac hot shorts are not credible circuit failures for valves that do not constitute a high-low pressure interface (References: Question 5.3.1 of Enclosure 2 to NRC Generic Letter 86-10, Item E of Bin 3 circuit failures in NRC Regulatory Issue Summary 2004-03, Risk-Informed Approach For Post-Fire Safe-Shutdown Associated Circuit Inspections).

Joseph M. Farley Nuclear Plant Units 1 and 2
Response to Request for Additional Information Related to
Request to Revise Service Water Intake Structure Exemption From Fire Protection Requirements at Farley Nuclear Plant

Enclosure 2

SWIS Fire Modeling

A.1 Service Water Intake Structure Description

The SWIS is a concrete building that is located partially below grade. The focus of this analysis is on Fire Area 72, which contains five fire zones. The five fire zones are as follows:

- Zone 72A – Service Water Pump Deck and Strainer Pit;
- Zone 72B – Switchgear Room (Train B);
- Zone 72C – 5kV Disconnect Switch Room (Train B);
- Zone 72D – 5kV Disconnect Switch Room (Train A); and
- Zone 72E – Switchgear Room (Train A).

The location of the SWIS fire zones is shown in Figure A–1.
The wall and associated penetrations and openings separating Fire Zone 72A from Fire Zones 72B, 72C, 72D, and 72E will be upgraded to a three hour fire rated barrier. Similarly, the wall separating Fire Zone 72C from Fire Zone 72D will be upgraded to a three hour fire rated barrier, effectively dividing Fire Area 72 into three fire areas. The new fire areas will be comprised of the following existing Fire Zones:

- Fire Zone 72A;
- Fire Zone 72B and Fire Zone 72C; and
- Fire Zone 72D and Fire Zone 72E.

The new fire areas will not be considered further.

There are two additional fire areas in the SWIS (Fire Area 73 and Fire Area 74) that are located south of Fire Zones 72C and 72D. The fire areas are also in Figure A–1. Because there are no Kaowool raceway issues associated with Fire Areas 73 and 74 that are applicable to this evaluation, the fire areas are not considered further.

Power cables in the SWIS are contained in conduit and other cables carry signal and control loads, thus they have a very low likelihood of initiating a fire. Except as noted in the detailed analysis below, all cables in the SWIS are thermoset (IEEE 383 qualified) and are not expected to support or propagate a cable tray fire.

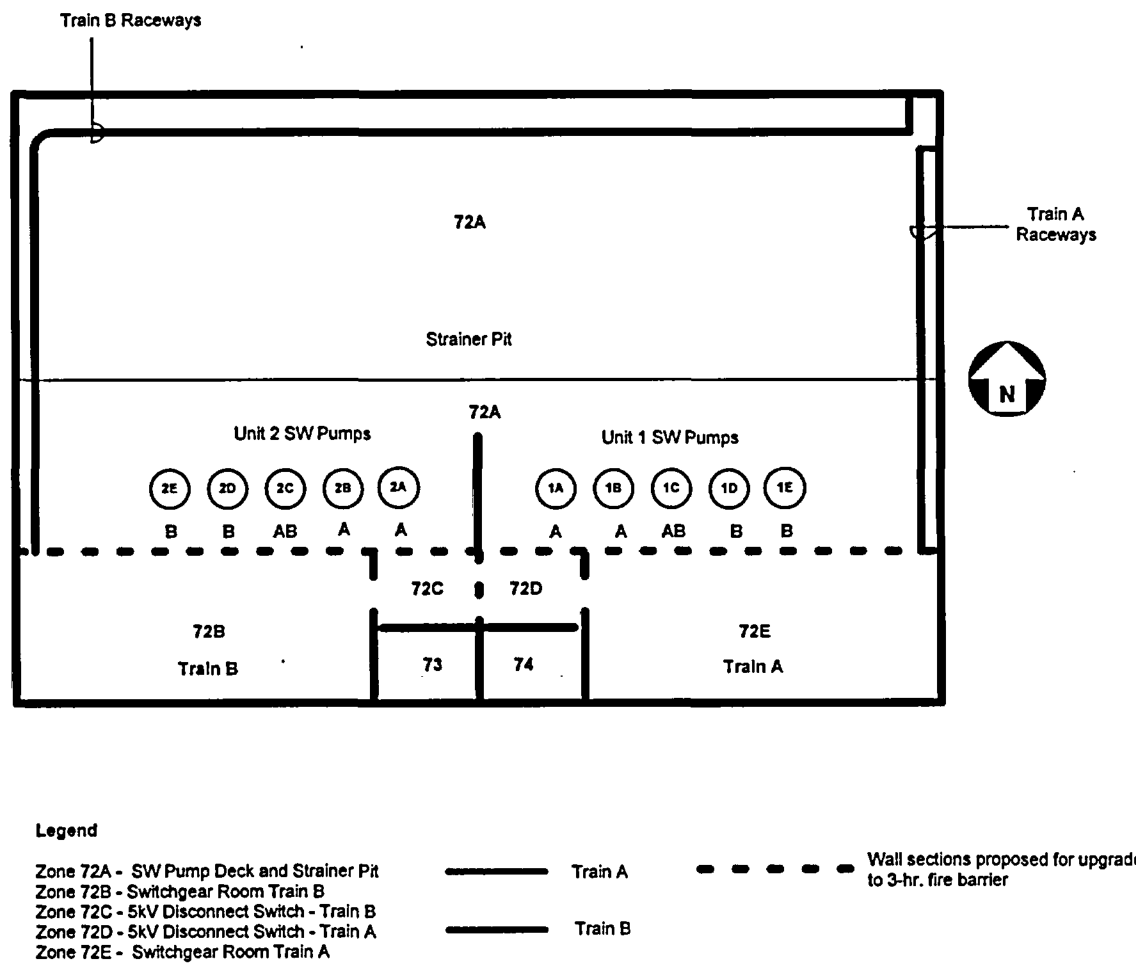


Figure A–1. Fire Area 72 – Service Water Intake Structure Simplified Layout (Not to scale)

A.1.1 Fire Zone 72A – Service Water Strainer Pit and Pump Deck

A.1.1.1 Physical Description

Fire Zone 72A is a bi-level space containing pumps, piping, cables, controls and related equipment associated with the Service Water system. The floor elevation of the lower level (the Strainer Pit) is 50.9 m (167 ft) [Drawing D-171331, 1983]. The floor elevation of the upper level (the Pump Deck) is 57.6 m (188.8 ft) or about 6.63 m (21 ft) above the floor of the Strainer Pit [Drawing D-171331, 1983]. The elevation of the base of the roof assembly (bottom of the concrete beams) is approximately 61 m (200 ft); the elevation of the top of the roof assembly (reinforced concrete units) is 62.2 m (204.2 ft) [Drawing D-171331, 1983]. The concrete beams are approximately 1 m (3 ft) tall and divide the ceiling space into cell-like regions, or beam pockets. The ceiling elevation between the Service Water pumps and the south wall is approximately 4 m (13 ft) above the floor due to the concrete beams in the vicinity.

The Strainer Pit is 27.7 m (91 ft) wide (east-west) by 14.4 m (47.3 ft) (north-south) long. About a quarter of the Strainer Pit lies beneath the Pump Deck; the remaining portions are directly below the SWIS roof assembly [Drawing D-171337, 1989]. The Pump Deck is about 27.7 m (91 ft) wide (east-west) by 7.5 m (24.6 ft) (north-south) long. Access to the Strainer Pit is via stairs from the Pump Deck located along the east wall of the SWIS. There are two doors that open onto the Pump Deck from the Disconnect Switch Areas. Each door is about 1.4 m (4.5 ft) wide and 2.1 m (7 ft) tall. The doors are normally closed and will have a 3- hour fire resistance rating after the wall separating the spaces is upgraded to three hours fire resistance.

The floors of the Pump Deck and the Strainer Pit are reinforced concrete. The floors are coated with a resin that contains less than 20 percent epoxy at application and typically has a dry film thickness of 0.2-0.4 mm (8-15 mils) [Ameron, 2002a; Ameron, 2002b; Ameron, 2003]. Test data on epoxy materials indicate that the critical heat flux is greater than 20 kW/m^2 (1.8 Btu/s-ft^2), significantly greater than pre-flashover heat fluxes on surfaces that are not immersed in the smoke layer [Sorathia et al., 1989; Steciak, 1985]. Additionally, the epoxy materials have a low flame spread potential. As such, the epoxy contribution to the combustible fuel load and the potential to spread fire on the epoxy coating is not considered significant.

There are several floor drains on the Pump Deck around the Unit 1 and Unit 2 Service Water pumps. Waste fluids are drained to a 10 cm (4 inch) header, which is also connected to floor drains in a trench system in Fire Zones 72B and 72E. The drain header carries waste fluid to a common sump in the center of the SWIS in the Strainer Pit. Because the header is located below the drains on the Pump Deck and Fire Zone 72B, combustible fluids would not travel between Fire Area 72A and Fire Areas 72B and Fire Area 72E. In addition, because there is no requirement for waste fluid drain lines to be equipped with flame arrestors [NFPA 30, 2000; NFPA 54, 2002; NFPA 69, 2002, and UL 525, 1994], it may be inferred that such drain lines are not a credible fire spread mechanism.

A.1.1.2 Contents

Fire Area 72A of the SWIS contains the Service Water pumps, the associated piping, valves, controls, and cables, the screen and booster pumps, and other such equipment.

The Unit 1 Train A and Train B Service Water pumps are located on the east half of the pump deck. Similarly, the Unit 2 Train A and Train B Service Water pumps are located on the west half of the Pump Deck. There is a concrete separation wall from floor to ceiling between the Unit 1 and Unit 2 pumps that is about 0.45 m (1.5 ft) thick [Drawing D-171344, 1982]. Each unit has five pumps: two A Train, two B Train, and one swing pump (A or B Trains). Each unit's pumps are separated from each other by 1.5 m (5 ft) on center. The plan view in Figure B–2 shows the locations of the pumps. There is a thermal radiation shield between the swing pump (C–Pump) and the adjacent pumps that extends vertically to about 2.1 m (7 ft) and horizontally to the edge of the pump as shown in Figure A-2.

The floor area around the Unit 1 and Unit 2 C–Pumps is partitioned from other areas by a 0.08 m (3 inch) high curb. Field measurements determined that the floor slopes away from the pumps to the north or south. Liquid is expected to pool near the south wall or to the north of the Service Water pumps. A new curb will be added between the south wall of the Pump Deck and the radiant shield that is between the Unit 1 E–Pump and the east wall of the SWIS. The curb will extend to the north edge of the Pump Deck and will be 0.08 m (3 inches) high. The base of the radiant shield will be sealed to the floor such that liquid would not seep under the shield. The new curb will isolate liquid spill fires associated with the Unit 1 D–Pump and E–Pump from pooling beneath the A Train cable tray located near the east wall.

The booster pumps for the Service Water system are also located on the Pump Deck in the southwest corner. The pumps are currently located near floor level and are separated by less than 0.3 m (1 ft).

The SWIS contains cable trays and conduit associated with the switchgear and the various pumps and equipment. The cable trays generally run along the perimeter within 3 m (10 ft) of the roof assembly. An exception to the cable tray location is the east-west cable trays located about 2 m (6 ft) north of the Service Water pumps. These trays do not contain targets and are not significant to this analysis, however. There is approximately 413 linear meters (1,356 linear feet) of cable tray raceways protected with Kaowool insulation. The remaining cables are either unprotected or are contained within conduit. To preclude the potential for fire spread along the west wall raceway, the PVC jacketed cable will be removed.

The Strainer Pit contains piping, valves, and other equipment associated with the Service Water system.

The most significant combustible fuel packages in the SWIS are as follows:

- Unit 1 Service Water pump lubrication oil – 85 L (22.5 gal) in each upper reservoir and 5.2 L (1.4 gal) in each lower reservoir;
- Unit 2 Service Water pump lubrication oil – 30.4 L (8 gal) in each upper reservoir and 1.4 L (0.4 gal) in each lower reservoir;
- Transient Class A combustible material, including trash bags, cleaning supplies, and plastic containers; and
- Cable jacket/insulation material.

The lubricant in the service water pumps is replaced every eighteen months. When this occurs, precautions should be implemented to prevent an increase in the quantity of lubricant associated with a single pump. This could be accomplished by removing the drained lubricant from the area prior to bringing the unused lubricant into Fire Zone 72A.

Nearly all cables in the SWIS have thermoset plastic jacket and insulation material and are not considered ignition sources per NRC [2004]. There are eight low-voltage PVC/PVC cables in a tray along the north and west wall that are thermoplastic. These cables are not located in trays containing cable targets under consideration in this evaluation. Based on Babrauskas [2004] and NUREG 1805 [2003], the autoignition temperature for the PVC/PVC cables is 263°C (505°F) and the critical ignition flux is about 15 kW/m² (1.3 Btu/s-ft²). To preclude these cables from acting as a fire propagation path, these cables along the west wall will be removed.

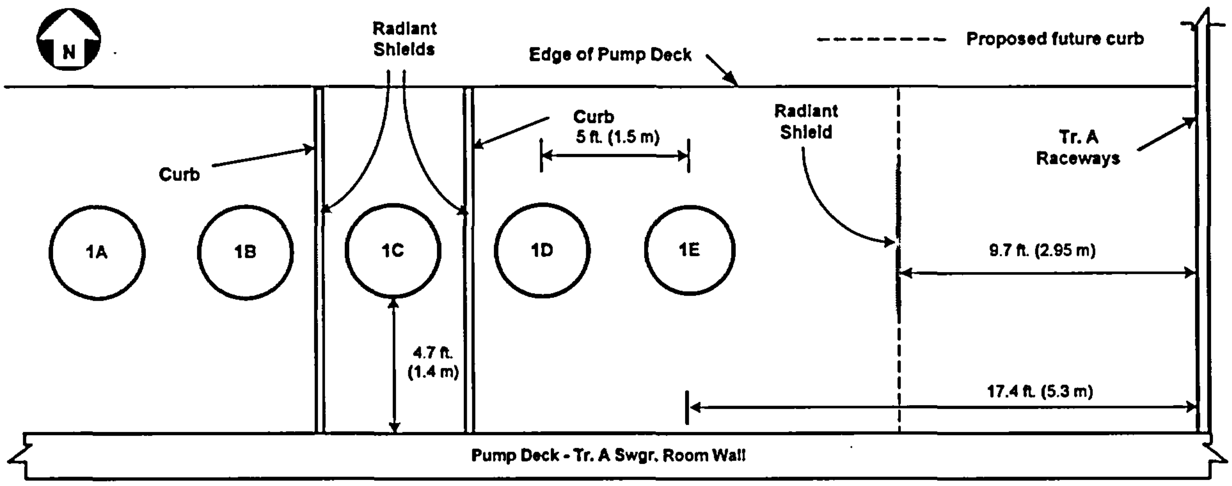


Figure A–2. SWIS Unit 1 Pump Deck (Simplified – Not to Scale)

A.1.1.3 Fire Protection Features

Fire Zone 72A has four fire protection systems:

- A preaction sprinkler system covering the entire floor area of the Pump Deck and the portions of the Strainer Pit that are not beneath the Pump Deck [Drawing D-180986, 1983].
- Directional Spray Pre-action Sprinkler protection system for each Service Water pump on the Pump Deck.
- Smoke detection.
- 3 hr fire barriers.

The Pump Deck Pre-action sprinkler systems (1SW-11A and 1SW-111B) are designed to provide 12.3 mm/min (0.3 gpm/ft²) coverage and uses 74°C (175°F) Grinnell EA-1 Protectospray nozzles [Drawing D-180986, 1983]. The sprinklers use an 8-mm (0.3 in) glass bulb for actuation [Grinnell, 1992]. The Response Time Index (RTI) for these sprinklers is 155 $m^{1/2}$-$s^{1/2}$ (281 $ft^{1/2}$-$s^{1/2}$) [Fleenor, 2002] when tested in accordance with International Organization for Standardization (ISO) Standard 6182 [ISO, 1993]. This RTI is consistent with standard response sprinklers and information available on glass bulb sprinklers [Puchovsky, 1996; Day Impex, 2003]. The valve to the sprinkler system is opened when there is a signal from the smoke detectors that are installed throughout the space.

Each Service Water pump is protected by directional spray sprinklers fed from the preaction system (1SW-111). The system is installed about 2 m (7 ft) above the Pump Deck floor and 1.2

m (4 ft) to 2.2 m (7 ft) below the ceiling assembly. The pump sprinklers use 74°C (175°F) Grinnell EA-1 Protectospray nozzles [Drawing D-170921, 1993] directed toward the pumps. Horizontal heat collectors measuring 0.3 m (1 ft) by 0.3 m (1 ft) are installed above the nozzles to prevent cold soldering from the systems at ceiling level. The system has been installed for local application protection per the NFPA 15 code for special hazard philosophy to provide water spray onto the SW pumps.

Fire Area 72A is also equipped with ionizing smoke detectors installed in accordance with NFPA 72E [1975].

Fire Zone 72A will be separated from other fire zones by a 3 hour fire rated barrier.

In addition to the four fire protection systems provided in the SWIS, there are three 4.7 m^3/s (10,000 cfm) exhaust ventilation fans located over the Unit 1 Service Water pumps and three located over the Unit 2 Service Water pumps. The fans are designed to remove excess heat around the Service Water pumps and normally operate when pre-set pump operating temperature levels are exceeded [Drawing D-170332, 1999]. Supply air is provided via leakage to adjacent spaces and the building exterior. The fans are also designed to actuate when heat detectors located near the pumps actuate [Drawing D-170333, 1986; Drawing D-170332, 1999]. They are not specifically designed to exhaust combustion products and are expected to fail if the temperature of the smoke layer is sufficiently hot.

A.2 Target Assumptions

A.2.1 Target Locations

The target locations in the SWIS were selected based on the potential for a fire to impact and disable both the A Train and B Train Service Water pumps for a particular unit. The critical failure mode for the Service Water pumps is the power cables, either in the cable trays or within junction boxes. The selection of the target therefore involved identifying where two cable tray trains, conduit, or junction boxes are nearest to each other relative to an assumed source fire. Four target locations are considered in this section of the analysis:

- Target 1: A and B Train cable trays in northeast corner of the Strainer Pit.
- Target 2: A Train cable tray near east wall of the Pump Deck (i.e., raceways AHR15C and AHR12C).
- Target 3: Pump motor junction boxes associated with the Unit 1 Service Water pumps.
- Target 4: Pump motor junction boxes associated with the Unit 2 Service Water pumps.

These locations are schematically shown in Figure A–3. Field measurements were taken to obtain exact location of the target relative to walls, potential source fires, and other fixed reference points. Note that there may be other locations where A and B Train cables trays, conduit or junction boxes could be impacted by a single source fire. Such locations are discussed in other sections of this document.

The northeast corner target is located 6.1 m (20 ft) above the floor of the Strainer Pit, the minimum elevation of the A and B Train cable trays that enter the SWIS at that location. The A Train cable tray continues along the east wall of the SWIS and the B Train cable tray continues along the north wall.

The target located near the east wall of the Pump Deck is a horizontal A Train cable tray that is 2.6 m (8.5 ft) above the floor of the Pump Deck. The west edge of the tray is about 2 m (6.5 ft) from the east wall of the SWIS and 5.3 m (17.4 ft) from the centerline of the Unit 1 Service Water E-Pump.

The Unit 1 pump motor junction boxes are located on the south side of each pump about 1.6 m (5.1 ft) above the floor, except for Service Water A-Pump motor junction box, which is 1.5 m (5.8 ft) above the floor. The boxes are 0.53 m (21 inches) by 0.37 m (14.5 inches) by 0.32 m (12.75 inches) deep. The pump motor junction boxes are collectively a target only when four or more motor boxes may be impacted by a single source fire. This is because the success criteria allows for a single pump to remain operational; however, one pump is assumed to be out of service.

The Unit 2 pump motor junction boxes are located on the south side of each pump about 2.1 m (7 ft) above the floor, except for Service Water C-Pump motor junction box, which is 1.8 m (6 ft) above the floor. The boxes are 0.37 m (14.5 inches) by 0.53 m (21 inches) by 0.32 m (12.75 inches) deep. The pump motor junction boxes are collectively a target only when four or more motor boxes may be impacted by a single source fire.

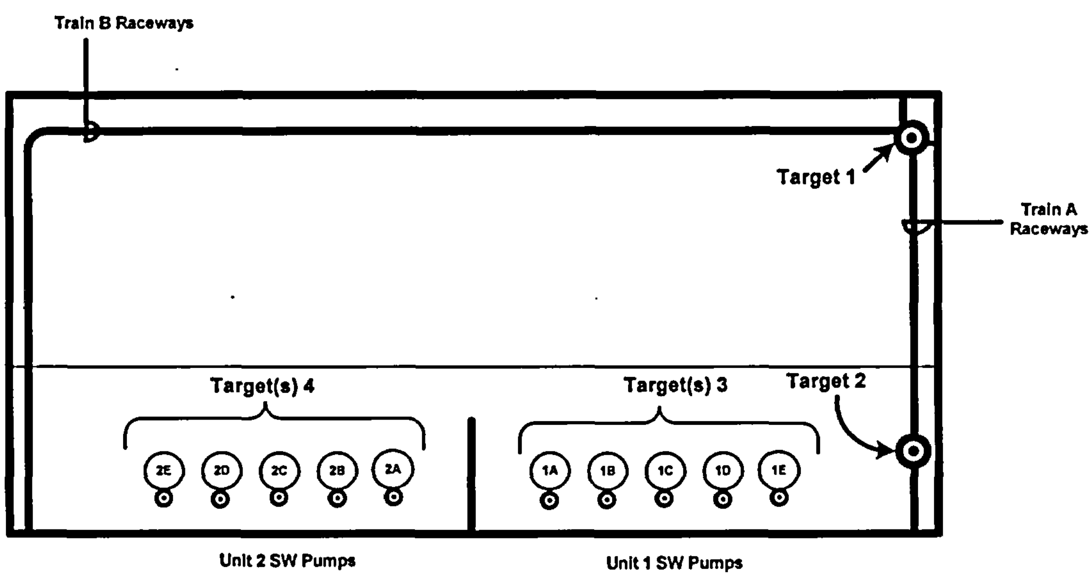


Figure A–3. SWIS Pump Deck & Strainer Pit – Fire Modeling – Target Locations (Simplified – Not to Scale)

A.2.2 Target Damage Criteria

All targets in the Service Water Intake Structure involve thermoset cables. In addition, since there are no thermoplastic cables intermixed with the thermoset target cables, damage thresholds based on thermoset cables is appropriate. As such, target damage is assumed when a surface temperature of 330°C (625°F) is attained [Nuclear Regulator Commission, 2004]. Note that this is lower than the threshold value 371°C (700°F) recommended in previous guidance documentation [Electric Power Research Institute (EPRI), 1993; Tewarson et al., 1979].

A target is assumed to exceed the damage threshold in this evaluation under the following circumstances:

- Exposure to flashover conditions – the smoke layer temperature exceeds 500°C (932°F) [Walton et al., 2002].
- Exposure to direct flame impingement.
- Exposure to an ambient temperature (smoke layer) greater than 330°C (625°F) for an indefinite time period (screening condition).
- Exposure to a radiant heat flux of 11.4 kW/m^2 (1.0 $Btu/s\text{-}ft^2$) for an indefinite time period [NRC, 2004].
- Exposure to a radiant heat flux and/or an ambient temperature that causes the target surface temperature to increase to 330°C (625°F) within a finite time period.

As a means of screening the target responses, an ambient temperature greater than 330°C (625°F) or a radiant heat flux greater than 11.4 kW/m^2 (1.0 $Btu/s\text{-}ft^2$) is used as the target threshold damage criteria. In specific cases, a greater degree of accuracy may be attained by calculating the transient temperature response of the target surface using the computer model HEATING7 version 7.3 [Childs, 1998], given the radiant and convective heat flux boundary conditions. Refer to Section A.8 for a discussion of the thermal model HEATING7.

Damage to the Service Water pumps is assumed if the pump motor junction boxes exceed the target criteria for cables as listed above. Although not explicitly evaluated, the criterion also applies to the cables that supply the pump motor junction boxes. Other portions of the pump are expected to have a greater damage threshold because the motor is contained within a metal housing.

A.3 Maximum Expected Fire Scenarios (MEFSs)

The Maximum Expected Fire Scenarios are identified by considering the fire types that have a reasonable likelihood of occurrence [NFPA 805, 2001]. The MEFS events are those that have the greatest potential to impact a particular target. Multiple MEFS events are possible in the SWIS because there are several target locations.

A.3.1 Fire Scenarios

A fire scenario is characterized in this section in terms of four parameters:

- The heat release rate;
- The duration;
- The fire area or equivalent diameter; and
- The flame height.

Quantification of these three parameters is necessary when assessing the impact the fire may have to a potential target. Note that the heat release rate may be the peak heat release rate or the transient heat release rate. In the latter case, the duration may refer to the duration at a particular heat release rate (i.e., the peak heat release rate) or the entire duration of the fire. Similarly, a fire with a transient heat release rate will have a transient flame height; the flame height of interest is typically the maximum flame height attained.

Because there are no targets evaluated in Fire Zones 72B, 72C, 72D, and 72E, all fire scenarios are located in Fire Zone 72A.

A.3.1.1 Scenario 1 – Transient Material in Northeast Corner of the Strainer Pit

Scenario 1 assumes a fire involving transient combustible material in the northeast corner of the Strainer Pit. This scenario was postulated based on the observation of transient combustible material in the SWIS area in general and the presence of a trash receptacle in the northeast corner in particular. It was thus assumed that a single trash bag was removed from the receptacle and staged at the bottom of the stairs.

Combustible Material Properties

The trash is assumed to consist of an equal mix (volumetric) of paper and plastic. The only material property that is necessary in this analysis of this scenario is the heat of combustion. The average heat of combustion for typical plastic materials is 30,300 kJ/kg (13,050 Btu/lb) [Tewarson, 2002] and the average heat of combustion for cellulose material is about 17,100 kJ/kg (7,370 Btu/lb) [Tewarson, 2002; Babrauskas, 2003]. The average heat of combustion is thus 23700 kJ/kg (10210 Btu/lb).

Heat Release Rate and Fire Duration

The heat release rate of a trash bag fire is a function of several variables, including the contents, the packing density, and the volume of the bag [Babrauskas, 2002; Lee, 1985]. Trash bag fire test show that the peak heat release rate may vary from less than 100 kW (95 Btu/s) to nearly 350 kW (332 Btu/s) [Lee, 1985; EPRI, 1995]. Figure A-4 shows that heat release rate profiles for three trash bag fire tests where the packing density ranged from 30 kg/m^3 (1.9 lb/ft^3) to 100 kg/m^3 (6.2 lb/ft^3) and the number of trash bags ranged from one to three [Lee, 1985; Babrauskas, 2002].

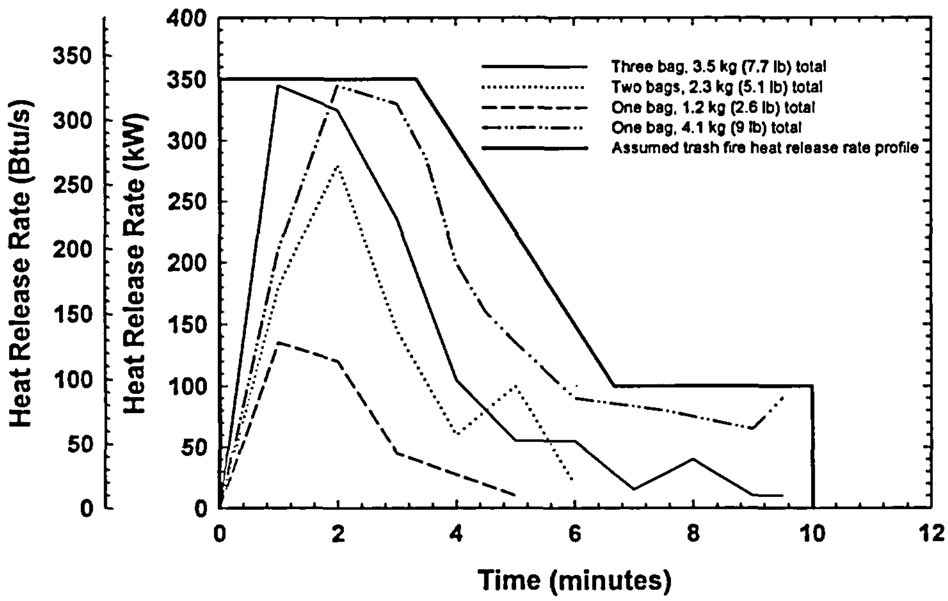


Figure A–4. Trash Fire Heat Release Rate Profiles [Babrauskas, 2002]

Based on a review of available data, the heat release rates shown in Figure A–4 are conservative yet realistic. As such, an assumed heat release rate profile for Scenario 1 is developed using the data shown in Figure A–4. The assumed energy release rate profile thus consists of three segments:

- 350 kW (332 Btu/s) for the first 200 seconds.
- A linear decrease from 350 kW (332 Btu/s) to 100 kW (95 Btu/s) between 200 seconds and 400 seconds after ignition (average heat release rate of 225 kW [213 Btu/s] for interval).
- 100 kW (95 Btu/s) between 400 seconds and 600 seconds after ignition.

Note that the heat release rate is considerably larger than the 50th and 95th percentile transient combustible fuel packages specified in the SDP [NRC, 2004], namely 70 kW (66 Btu/s) and 200 kW (190 Btu/s), respectively [NRC, 2004]. The fire duration is a function of the mass of fuel available and the heat release rate. NRC [2004] provides no guidance on estimating the fire duration; however, a ten minute source fire appears consistent with what would develop in the types of transients bound by the 50th and 95th percentile heat release rates.

The total mass of fuel consumed in the assumed trash fire heat release rate profile may be estimated using the following equation [Drysdale, 1999]:

$$M = \frac{\sum_{i=1}^{n} \dot{Q}_{a,i} \Delta t_i}{\Delta H_c} \qquad \text{(B–1)}$$

where M is the combustible mass consumed (kg [lb]), $\dot{Q}_{a,i}$ is the average heat release rate (kW [Btu/s]) over the time interval Δt_i (s), ΔH_c is the heat of combustion (23,700 kJ/kg [10,210 Btu/lb]), i is the number of time intervals, and n is the total number of time intervals. The total mass of combustible material consumed in the assumed heat release rate profile is thus 6.2 kg (13.6 lb) plus the percentage char that remains, which is a reasonable estimate for a typical industrial trash bag.

Consideration of transient fuel packages that may contain a greater quantity of combustible material or material with a different peak heat release rate is given in the sensitivity assessment for this scenario summarized in Section A3.2.2.

Fire Area and Effective Fire Diameter

The effective diameter of a trash bag fire is a function of the packing density and the peak heat release rate [Lee, 1985]. Trash bag packing densities for heat release rate tests ranged between 30 kg/m³ (1.9 lb/ft³) to 100 kg/m³ (6.2 lb/ft³) [Lee, 1985; Babrauskas, 2002]. Assuming a low trash bag packing density results in a lower effective diameter and consequently a larger heat release rate per unit area. Given this, a packing density of 30 kg/m³ (1.9 lb/ft³) is assumed for Scenario 1. The effective diameter that corresponds to this packing density and a peak heat release rate of 350 kW (332 Btu/s) is 0.6 m (2 ft). The resulting fire area is therefore 0.28 m² (3 ft²), which represents a unit heat release rate of about 1,250 kW/m² (110 Btu/s-ft²). Note that typical class A materials have unit heat release rates in the 200 – 600 kW/m² (17.6 – 53 Btu/s-ft²) range [Babrauskas, 2002; Babrauskas et al., 1992].

Flame Height

The continuous flame height for a corner fire is given by the following equation [Hasemi et al., 1984; McCaffrey, 2002]:

$$L_c = 3.0\dot{Q}^{*2/3} \cdot D \qquad \text{(B–2)}$$

where D is the equivalent fire diameter (m [ft]) and $\dot{Q}^*$ is a non-dimensional heat release rate given by the following equation [Hasemi et al., 1984]:

$$\dot{Q}^* = \frac{\dot{Q}}{\rho_o c_{p,o} T_\infty g^{1/2} D^{5/2}} \qquad \text{(B–3)}$$

and $\dot{Q}$ is the source fire heat release rate (kW [Btu/s]), ρ_o is the ambient air density (kg/m³ [lb/ft³]), $c_{p,o}$ is the ambient air heat capacity (kJ/kg-°C [Btu/lb-°F]), and g is the acceleration of gravity (9.8 m/s² [32.2 ft/s²]). The ambient air temperature is assumed to be 25°C (77°F) unless the smoke layer elevation is shown to be lower than the target, in which case the smoke layer temperature is assumed. If the ambient air temperature is 25°C (77°F), the ambient air density is about 1.2 kg/m³ (0.075 lb/ft³) and the ambient air heat capacity is 1.0 kJ/kg-°C (0.24 Btu/lb-°F) [Holman, 1990]. A transient corner fire with a peak heat release rate of 350 kW (332 Btu/s) and an equivalent diameter of 0.6 m (2 ft) would therefore have a continuous flame height of 2.8 m (9.2 ft).

Summary

Table A–1 summarizes the key parameters for Scenario 1.

Table A–1. Key Parameters for Scenario 1

Parameter	SI Units	English Units
Peak Heat Release Rate	350 kW	332 Btu/s
Fire Duration at Peak Heat Release Rate	200 seconds	200 seconds
Maximum Fire Duration	600 seconds	600 seconds
Continuous Flame Height	1.9 m	6.4 ft
Fire Area	0.28 m^2	3 ft^2
Equivalent Fire Diameter	0.6 m	2 ft

A.3.1.2 Scenario 2 – Unit 1 Service Water Pump Lubricant

Scenario 2 is a fire involving a Unit 1 Service Water pump lubrication spill. The largest single reservoir of oil is 85 L (22.5 gal) of Texaco Regal 68. A lubricant spill from a C–Pump would collect in the curb area around the C–Pump. A lubricant spill from a D–Pump or an E–Pump would collect in the curb area between the C–Pump and the radiant shield east of the E–Pump. A lubricant spill from an A-Pump or a B–Pump would be limited by the curb between the B-Pump and the C–Pump.

Because the floor slopes away from the pumps, lubricant would likely accumulate north and/or south of pump(s). Based on the target locations, the most severe fire exposures would involve a lubricant fire that is south of the pumps. Further, if it is assumed that the entire reservoir collects south of the pump(s), then the fire duration and resulting target impact is maximized.

Two sub-scenarios are considered:

- Scenario 2A: an 85 L (22.5 gal) lubricant spill from the Unit 1 C–Pump; and
- Scenario 2B: an 85 L (22.5 gal) lubricant spill from a Unit 1 E–Pump.

A lubricant spill that originates in a Unit 1 E–Pump is assumed to collect between the E–Pump and the future curb between the radiant shield and the south wall, maximizing the fire duration in the fuel. A lubricant spill that originates in a D–Pump is expected to accumulate in the area between curbs, thus decreasing the fire duration relative to the E–Pump fire scenario. Similarly, a lubricant spill that originates in an A–Pump or a B–Pump could spread west of the pump area, also decreasing the fire duration relative to the E–Pump fire scenario. This is especially true when noting that lubricant may form pools as thin as 1 mm (0.04 in) [Gottuk et al., 2002]. As a result, the E–Pump fire scenario bounds the A–, B–, and D–Pump fire scenarios and is therefore used to calculate the impact of a fire originating from these pumps on adjacent pumps.

Combustible Material Properties

The pump lubricant is Texaco Regal 68, a mix of mineral oil (liquid paraffin) and naphthenic oil [Chevron, 2002]. The material properties that are necessary for this evaluation are the density, the heat of combustion, and the unit heat release rate.

The density of Texaco Regal is 880 kg/m³ (54.9 lb/ft³) [Fuel and Marine Marketing, 1999]. The heat of combustion of hydrocarbon fuel oil, 39,700 kJ/kg (17,100 Btu/lb), is assumed for the Texaco Regal [Babrauskas, 2002]. The heat release rate per unit floor area is derived from the heat of combustion and the unit mass loss rate as follows [Gottuk et al., 2002]:

$$\dot{Q}'' = \dot{m}''\Delta H_c \qquad \text{(B–4)}$$

where $\dot{Q}''$ is the heat release rate per unit floor area (kW/m² [Btu/s-ft²]) and $\dot{m}''$ is the unit mass loss rate (kg/s-m² [lb/s-ft²]). The unit mass loss rate for hydrocarbon fuel oil is 0.035 kg/s-m² (0.0072 lb/s-ft²), such that the assumed unit heat release rate for the Texaco Regal 68 oil is 1,390 kW/m² (122 Btu/s-ft²).

Fire Area and Effective Fire Diameter

The fire area is determined by the location of the curbs, south wall, and the pumps. Based on field measurements, the total area enclosed by the curb south of the C–Pump measures 1.37 m (4.50 ft) by 1.42 m (4.67 ft) for total area of 1.95 m² (21 ft²). The maximum lubricant depth would be 4.4 cm (1.7 in), which is less than the 7.6 cm (3 in) curb height. The lubricant in the pumps is not pressurized and would therefore collect around the base of the pump. A lubricant spill originating from an E–Pump spill is assumed to occupy the area between the E-Pump and the future curb between the radiant shield and the south wall. It is likely that some lubricant would be directed toward the north of this area, however the burning duration of a fire would decrease without a significant increase in the emissive power of the fire or the view factor between a target and the fire. Based on field measurements, the total area of the region where lubricant from an E–Pump is assumed to accumulate is 3.9 m² (42 ft²).

The effective diameter for a C–Pump lubricant fire scenario, assuming a total fire area of 1.95 m² (21 ft²) is 1.6 m (5.2 ft). Likewise, the equivalent diameter for an E-Pump lubricant fire scenario, assuming a total fire area of 3.9 m² (42 ft²) is 2.2 m (7.3 ft).

Heat Release Rate and Fire Duration

The heat release rate of a liquid pool fire is given by the following equation:

$$\dot{Q} = \dot{Q}''A \qquad \text{(A–5)}$$

where A is the area of the pool (m² [ft²]) and the unit heat release rate for the lubricant is 1,390 kW/m² (122 Btu/s-ft²) as described above.

The heat release rate for a C–Pump lubricant fire scenario, assuming a total fire area of 1.95 m² (21 ft²) is thus 2,710 kW (2,570 Btu/s) and the heat release rate for an E–Pump lubricant fire scenario, assuming a total fire area of 3.9 m² (42 ft²) is 5,420 kW (5,140 Btu/s).

The fire duration is a function of the total quantity of fuel available and the heat release rate as follows [Drysdale, 1999]:

$$t_d = \frac{\Delta H_c \rho V}{\dot{Q}} \qquad \text{(B–6)}$$

where t_d is the fire duration (s) and V is the volume of lubricant (m³ [ft³]).

The fire duration for a C—Pump lubricant fire scenario, assuming 85 L (22.5 gal) of lubricant and a peak heat release rate of 2,710 kW (2,570 Btu/s) is 1,096 seconds (18.3 minutes). The fire duration for an E-Pump lubricant fire scenario, assuming 85 L (22.5 gal) of lubricant and a peak heat release rate of 5,420 kW (5,140 Btu/s) is 548 seconds (9.1 minutes). The heat release rate profiles for the Scenarios 2A and 2B are shown in Figure A-5.

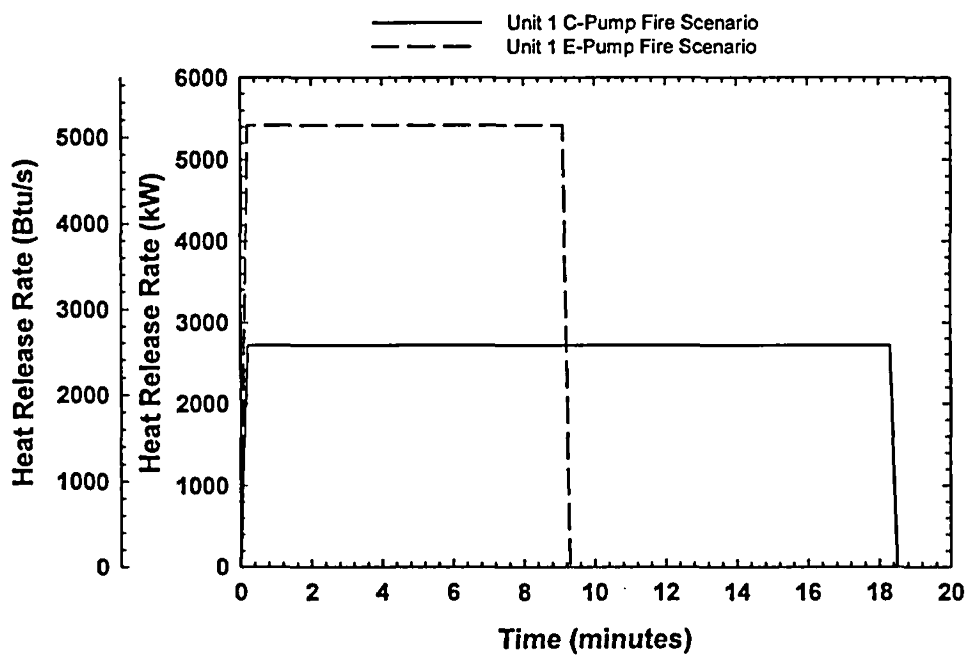


Figure A–5. Unit 1 C-Pump and E-Pump Lubricant Fire Scenario Heat Release Rate Profiles

Flame Height

The maximum flame height for a pool fire against a wall is given by the following equation [Beyler, 1986; Hasemi et al., 1984]:

$$L_f = 0.21\dot{Q}^{2/5} \quad (SI)$$
$$L_f = 0.70\dot{Q}^{2/5} \quad (English) \qquad \text{(A–7)}$$

provided that the following condition is met [Hasemi et al., 1984]:

$$11.4 < \frac{\dot{Q}^{2/5}}{D} < 21.7 \quad (SI)$$
$$3.4 < \frac{\dot{Q}^{2/5}}{D} < 6.47 \quad (English) \qquad \text{(A–8)}$$

where all terms have been previously defined. The condition specified by Equation A–8 is met for both Scenario 2A and Scenario 2B. The flame height calculated for Scenario 2A using Equation A–7 is 5 m (16 ft) and the calculated flame height for Scenario 2B is 6.5 m (21 ft). The maximum ceiling height in the area of the Service Water pumps is about 4.0 m (13 ft) [Drawing D-171331, 1983], thus flame impingement on the ceiling and potential flame extension under the ceiling is possible. However, because the ceiling areas are segmented by the concrete beams and the large number of obstructions above the 3 m (10 ft) elevation, this effect is not expected to have a significant impact on the calculation results.

Summary

Table A–2 summarizes the key parameters for Scenarios 2A and 2B.

Table A–2. Key Parameters for Scenarios 2A and 2B

Parameter	Scenario 2A – C-Pump Lubricant Fire		Scenario 2B – E-Pump Lubricant Fire[1]	
	SI Units	English Unit	SI Units	English Units
Peak Heat Release	2,710 kW	2,570 Btu/s	5,420 kW	5,140 Btu/s
Fire Duration	18.3 min	18.3 min	9.1 min	9.1 min
Flame Height	4.0 m (at ceiling)	13 ft (at ceiling)	4.0 m (at ceiling)	13 ft (at ceiling)
Fire Area	1.95 m²	21 ft²	3.9 m²	42 ft²
Effective Diameter	1.6 m	5.2 ft	2.2 m	7.3 ft

[1]Scenario used to evaluate impact of Unit 1 A-, B-, and D-Pump fires on adjacent pumps

A.3.1.3 Scenario 3 – Unit 2 Service Water Pump Lubricant

Scenario 3 is a fire involving a Unit 2 Service Water pump lubrication spill. The largest single reservoir of oil is 30 L (8 gal) of Texaco Regal 68. A lubricant spill from a C-Pump would collect in the curb area around the C–Pump and a lubricant spill from an A–, B–, D–, or E–Pump would collect adjacent to the curb area. Because the floor slopes away from the pumps, lubricant would accumulate north and/or south of pump(s). Based on the target locations, the most severe fire exposures would involve a lubricant fire that is south of the pumps. Further, if it is assumed that the entire reservoir collects south of the pump(s), then the fire duration and resulting target impact is maximized.

Two sub-scenarios are considered:

- Scenario 3A: a 30 L (8 gal) lubricant spill from the Unit 2 C–Pump; and
- Scenario 3B: a 30 L (8 gal) lubricant spill from a Unit 2 A–, B–, D–, or E–Pump.

Combustible Material Properties

The Unit 2 Service Water pump lubricant is Texaco Regal 68. The combustible material properties are as described in Section A.3.1.1.

Fire Area and Fire Diameter

The fire area is determined by the location of the curbs, south wall, and the pumps. Based on field measurements, the total area enclosed by the curb south of the C–Pump measures 1.22 m (4.0 ft) by 1.37 m (4.5 ft) for total area of 1.67 m² (18 ft²). A lubricant spill originating from an A-, B-, D-, or E-Pump would be limited only by the south wall and the curbs around the C–Pump. Based on liquid spread data, liquid pools may be as thin as 1 mm (0.04 in) [Gottuk et al., 2002]. Thus duration of such a fire would be short and the impact on adjacent pumps would be reduced. A conservative estimate of the lubricant spill area is thus based on the Unit 1 E-Pump lubricant spill area, which is confined by an additional curb. The spill area in this case is nearly twice that of the Unit 1 C–Pump. As such, the assumed spill area for a Unit 2 A–, B–, D–, or E–Pump is assumed to be twice that of the Unit 2 C–Pump, or 3.3 m² (36 ft²). This assumption results in an increase in the fire duration without having an impact on the fraction of radiation calculated to reach a target and is thus conservative.

Heat Release Rate and Fire Duration

The heat release rate and fire duration for the Unit 2 pump lubricant fire scenarios was calculated using Equations A–5 and A–6.

The heat release rate for a C–Pump lubricant fire scenario, assuming a total fire area of 1.67 m² (18 ft²) is thus 2,320 kW (2,200 Btu/s) and the heat release rate for an A–, B–, D–, or E–Pump lubricant fire scenario, assuming a total fire area of 3.3 m² (36 ft²) is 4,640 kW (4,400 Btu/s).

The fire duration for a C–Pump lubricant fire scenario, assuming 30 L (8 gal) of lubricant and a peak heat release rate of 2,320 kW (2,200 Btu/s) is 455 seconds (7.6 minutes). The fire duration for an A–, B–, D–, or E–Pump lubricant fire scenario, assuming 30 L (8 gal) of lubricant and a peak heat release rate of 4,640 kW (4,400 Btu/s) is 227 seconds (3.8 minutes). The heat release rate profiles for the Scenarios 3A and 3B are shown in Figure A–6.

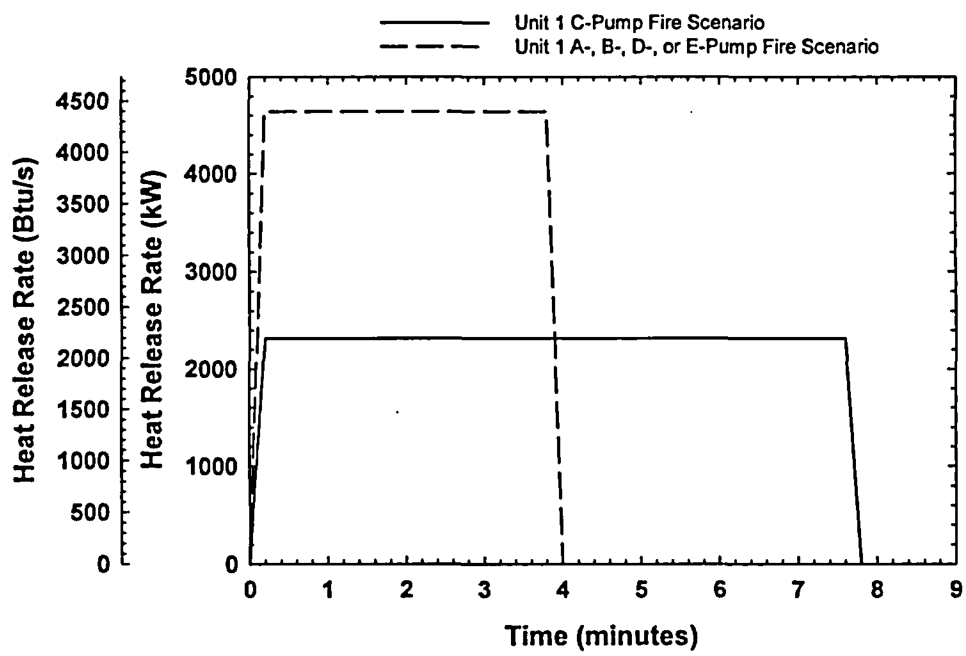


Figure A–6. Unit 2 Service Water Pump Lubricant Fire Scenario Heat Release Rate Profiles

Flame Height

The maximum flame height for a pool fire against a wall is given by Equation A-7, provided that the condition described by Equation A–8 is met.

The condition specified by Equation A–8 is not met for either Scenario 3A or Scenario 3B, however the difference is small suggesting that the calculated flame heights may still be used as a rough estimate. The flame height calculated for Scenario 3A using Equation A–7 is 4.7 m (15 ft) and the calculated flame height for Scenario 3B is 6.2 m (20 ft). The maximum ceiling height in the area of the Service Water pumps is about 4.0 m (13 ft) [Drawing D-171331, 1983], thus flame impingement on the ceiling is assumed for both scenarios.

Summary

Table A–3 summarizes the key parameters for Scenarios 3A and 3B.

Table A-3. Key Parameters for Scenarios 3A and 3B

Parameter	Scenario 3A – C-Pump Lubricant Fire		Scenario 3B – A–, B–, D–, or E-Pump Lubricant Fire	
	SI Units	English Unit	SI Units	English Units
Peak Heat Release	2, 320kW	2,200 Btu/s	4,640 kW	4,400 Btu/s
Fire Duration	7.6 min	7.6 min	3.8 min	3.8 min
Flame Height	4.0 m (at ceiling)	13 ft (at ceiling)	4.0 m (at ceiling)	13 ft (at ceiling)
Fire Area	1.67 m²	18 ft²	3.3 m²	36 ft²
Effective Diameter	1.5 m	4.8 ft	2 m	6.7 ft

A.3.2 Results

This section describes the impact of the postulated fire scenarios on specific targets. The goal is to determine if a postulated fire scenario can cause a target to exceed the critical temperature of 330°C (625°F) as described in Section A.2. The method used to determine this varies, depending on the manner in which the fire is assumed to impact the target.

A.3.2.1 Methodology

The exposure temperature and/or heat flux at the surface of a target is determined as means of identifying scenarios that require further analysis. Fire scenarios that do not expose the target to a temperature greater than 330°C (625°F) or a radiant heat flux greater than 11.4 kW/m² (1 Btu/s-ft²) are not assumed to adversely impact a target. The following specific methods may be used to estimate the temperature/flux at the target surface:

- CFAST [Jones et al., 2000] – calculates the smoke layer temperature and elevation;
- Thermal plume correlations – calculates the plume temperature at a specific elevation above the fire; and
- Thermal radiation calculations – calculates the radiant heat flux at a fixed position relative to a source fire.

The computer model CFAST [Jones et al., 2000] is used to calculate the smoke layer temperature and elevation above the floor for all scenarios considered. A scenario that causes flashover in a space or a smoke layer temperature greater than 330°C (625°F) may be capable of having an effect on all targets. Otherwise, the scenario is assumed to affect only those targets that are located nearby. Section A.7 contains a description of CFAST, a summary of key input parameters for the various scenarios, and the input files used in this analysis.

The exposure temperature for a target that is located directly above a fire is estimated using thermal plume temperature correlations. Correlations are available for fires located near walls and in corners as well as for fires that are in the open. If the smoke layer immerses a target, the combined impact of the thermal plume and smoke layer are evaluated. The maximum heat flux to a target against a flat wall for a fire in a corner would be less than 7.2 kW/m² (0.63 Btu/s-ft²) above the flame tip [Lattimer et al., 2003], thus it is conservative to assume immersion in the thermal plume.

The radiant heat flux at the surface of a target is calculated for those that are not located directly above a fire, but are located such that they intercept thermal radiation from the fire. If the smoke layer immerses a target, the combined impact of the convective heat flux from the smoke layer and radiant heat flux from the fire is assessed. The latter case only applies if the target is near enough to the source fire such that the smoke layer does not absorb the thermal radiation from the fire.

Where the temperature or heat flux at the surface of the target exceeds the critical values of 330°C (625°F) or 11.4 kW/m² (1 Btu/s-ft²), a more detailed transient analysis is performed. This is accomplished using the computer model HEATING7 version 7.3 [Childs, 1998], a thermal heat transfer model. Section A.8 contains a description of HEATING7, a summary of key input parameters for the various scenarios evaluated, and all input files used in this analysis.

As noted in Section A.1.1.1, the ceiling of the SWIS structure is subdivided by 1m (3 ft) thick beams into a series of cells or beam pockets. Beam pockets would likely interrupt the ceiling jet flow and could impact the actuation time of detection devices located at the ceiling or the exposure temperature to targets within the beam pocket or the ceiling itself. The beam pockets are not expected to have a significant influence on the overall smoke layer formation because there is a sufficient volume of smoke generated to completely fill the beam pockets and descend to lower elevations. Since there are no targets within the beam pockets and detection is not credited for the scenario evaluated, the presence of beam pockets would not change the results or conclusions applicable to this scenario.

As part of the defense-in-depth, potential for sprinkler system actuation is evaluated for each scenario though actuation is not directly credited with mitigating the effects of a fire scenario. Beam pockets in the SWIS would likely influence the actuation of the sprinkler and detection systems [Koslowsi et al., 1992]. The effect may be an increase or decrease in the actuation time relative to a flat ceiling, depending on the location of the sprinkler in the beam pocket and the fire centerline. This effect is not directly modeled in this section; however, sprinkler actuation under a range of temperature and velocity conditions that would bracket the conditions in the beam pockets are considered. These conditions range from a nearly stagnant smoke layer to a typical ceiling jet.

The performance of the sprinkler system once it actuates is not specifically addressed in this evaluation. It is reasonable to assume that as a minimum, if the sprinklers actuate and wet the target that is not within the fire region (i.e., exposed only to the radiant heat flux), then the potential for the target surface temperature to exceed 330°C (625°F) would be greatly reduced.

A.3.2.2 Scenario 1

Scenario 1 is a miscellaneous Class A combustible material fire (trash bag) located in the northeast corner of the SWIS on the Strainer Pit elevation.

Targets

The Train A and Train B cable trays that enter the SWIS in the northeast corner and continue along the east and north walls is the only target that is local to Scenario 1. The lowest elevation for cables entering the building is about 6.1 m (20 ft); the minimum elevation of thermoplastic cables is about 10.9 m (36 ft) above the floor of the strainer pit. Because the thermoplastic cable tray targets are above the thermoset cable tray targets, the only impact of igniting them would be an increase in the heat release rate in the SWIS. The remaining targets in the SWIS would only be impacted by Scenario 1 if the smoke layer temperature exceeds 500°C (932°F) (i.e., flashover) or if the smoke layer temperature exceeded 330°C (625°F) and the targets were immersed in the smoke layer.

Smoke Layer Calculations

The smoke layer elevation and temperature in the SWIS for Scenario 1 was calculated using CFAST [Jones et al., 2000]. The heat release rate for this fire scenario is described in Section A.3.2.1 and shown in Figure A–4. Section A.7 contains a description of the input parameters for the model. The results are shown in Figure A–7 (temperature) and Figure A–8 (smoke layer elevation).

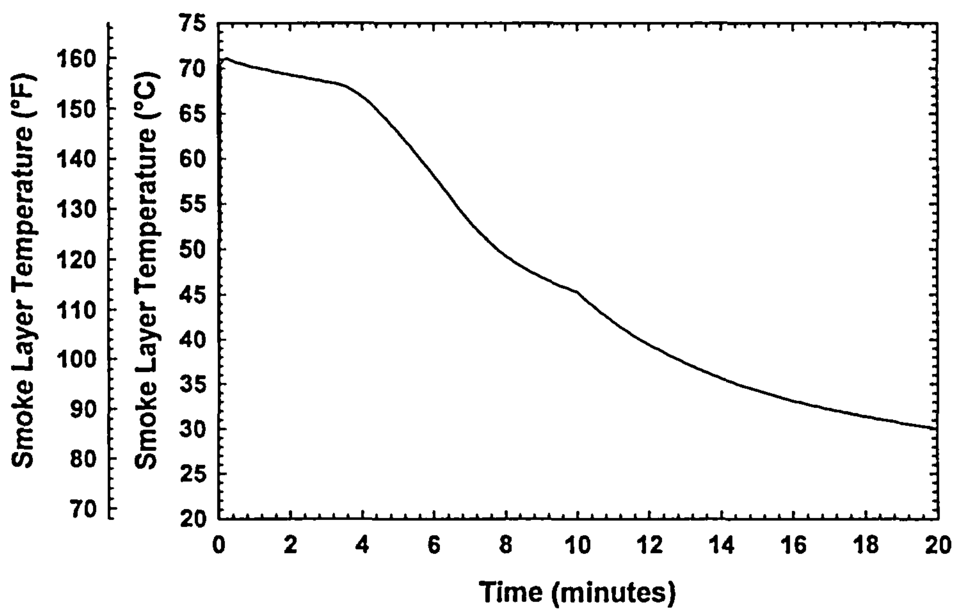


Figure A–7. Smoke Layer Temperature in Fire Area 72A – Transient Class A Fire Scenario

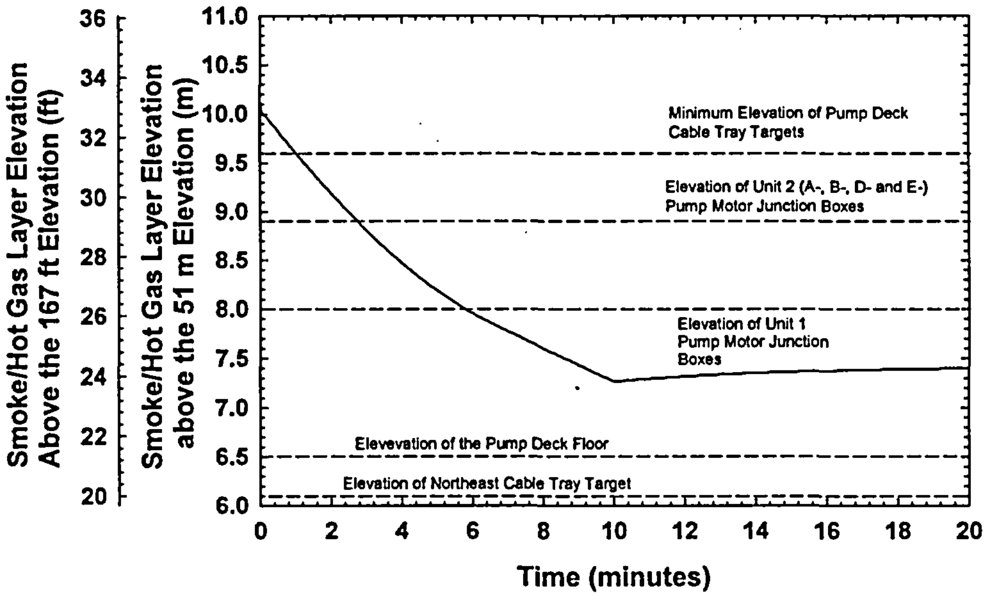


Figure A–8. Smoke Layer Elevation in Fire Area 72A – Transient Class A Fire Scenario

Figure A–7 indicates that only the cable tray targets on the Pump Deck and the Unit 1 and Unit 2 Service Water motor junction boxes would be immersed by the smoke layer. Further, Figure A–8 shows that the maximum temperature of the smoke layer is about 70°C (158°F), significantly less than the minimum temperature for flashover, the critical target surface temperature of thermoset cable targets (330°C [625°F]), and the autoignition temperature of PVC cables (263°C [505°F]).

Localized Target Exposure

The exposure temperature to the target cable trays in the northeast corner of the SWIS was calculated assuming that the fire is located in the corner. The exposure mechanism to the target in this case is immersion in the thermal plume. The temperature of a corner fire thermal plume as a function of elevation is given by the following equation [Hasemi et al., 1984]:

$$T = T_{\infty} + \frac{5100}{Z'^{5/3}} \quad (SI)$$
$$T = T_{\infty} + \frac{9180}{Z'^{5/3}} \quad (English) \qquad \text{(A–9)}$$

provided that:

$$Z' \geq 3.6 \qquad \text{(A–10)}$$

and:

$$T = T_\infty + \frac{2200}{Z'} \qquad (SI)$$
$$T = T_\infty + \frac{3960}{Z'} \qquad (English) \qquad \text{(A–11)}$$

provided that:

$$2.5 \le Z' < 3.6 \qquad \text{(A–12)}$$

where T is the exposure temperature (°C [°F]), T_∞ is the ambient temperature (°C [°F]), and Z' is a non-dimensional elevation given by the following equation [Hasemi et al., 1984]:

$$Z' = \frac{Z + \Delta z}{\dot{Q}^{*2/5} D} \qquad \text{(A–13)}$$

where Δz is the depth of the point source heat release that would produce a similar thermal plume as that which is burning (m) and $\dot{Q}^*$ is a non-dimensional heat release rate as determined using Equation A–3. The point source equivalent depth is found using the following equation for corner fires [Hasemi et al., 1984]:

$$\Delta z = D \cdot (3.54 \dot{Q}^{*2/5} - 3.3 \dot{Q}^{*2/3}) \qquad \text{(A–14)}$$

where all terms have been defined previously. The non-dimensional heat release rate is given by the following equation [Hasemi et al., 1984]:

$$\dot{Q}^* = \frac{\dot{Q}}{\rho_o c_{p,o} T_\infty g^{1/2} D^{5/2}} \qquad \text{(A–15)}$$

where ρ_o is the ambient air density (kg/m^3 [lb/ft^3]), $c_{p,o}$ is the ambient air heat capacity (kJ/kg-°C [Btu/lb-°F]), and g is the acceleration of gravity (9.8 m/s^2 [32.2 ft/s^2]). The ambient air temperature is assumed to be 25°C (77°F) for the Train A cable tray target because the smoke layer elevation is greater than the target elevation. Likewise, the ambient air temperature is assumed to be 70°C (158°F) for the Train B cable target containing thermoplastic cables, since the smoke layer rapidly immerses the trays near the ceiling. The ambient air density is about 1.2 kg/m^3 (0.075 lb/ft^3) for the Train A cable targets and 1.0 kg/m^3 (0.063 lb/ft^3) for the Train B cable targets. The ambient air heat capacity is approximately 1.0 kJ/kg-°C (0.24 Btu/lb-°F) for both targets [Holman, 1990].

The Train A cable tray target elevation in this area is 6.1 m (20 ft) above the base of the fire. The heat release rate and the fire diameter are 350 kW (332 Btu/s) and 0.6 m (2 ft), respectively. The exposure temperature from the fire at the target elevation is therefore 138°C (280°F), significantly lower than the critical exposure temperature of 330°C (625°F). The flame height for this fire scenario is less than the target height, thus the maximum heat flux at the wall surface would be less than 7.4 kW/m^2 (0.65 Btu/s-ft^2) [Lattimer et al., 2003]. The maximum thermal plume exposure temperature to the Train B cable trays would be 114°C (237°F). Because the temperature is lower at the Train B cable trays containing PVC, and the trays are above the target raceways, the results of the Train A calculations are bounding.

Suppression System Actuation

The Strainer Pit is equipped with pre-action sprinklers with an actuation temperature of 79°C (175°F) [Drawing D-180986, 1983]. As noted in Section A.1.1.3, the assumed RTI for the sprinkler model installed in the SWIS is 155 $m^{1/2}$-$s^{1/2}$ (281 $ft^{1/2}$-$s^{1/2}$) based on information provided by the distributor [Fleenor, 2002].

The potential for the suppression system to actuate was estimated using the temperature results of the smoke layer and the thermal plume. The ceiling in the SWIS consists of a number of bays that are expected to interfere with the development of a smoke layer. In addition, the fire scenario considered is located in a corner. Computer models are available for calculating the sprinkler response time [*e.g.*, DETACT (Portier et al., 1996; Alpert, 1972)], however such models may not adequately address ceiling obstructions or the corner fire configuration.

The sprinkler actuation equations were solved directly for various ambient temperatures and assumed local air velocities. Section A.9 contains a description of the equations used to estimate the sprinkler actuation time and the input assumptions. The local air velocities assumed range from a nearly still 0.1 m/s (0.3 ft/s) to a typical plume velocity of about 2 m/s (6.6 ft/s). The exposure temperature range for Scenario 1 is 70°C (158°F) (smoke layer heating only) to about 131°C (268°F) (maximum plume temperature prior to interaction with smoke layer). Sprinklers would not actuate in the latter case, whereas the actuation time in the former would be in the 1 – 2 minute range, as seen in Figure A–9.

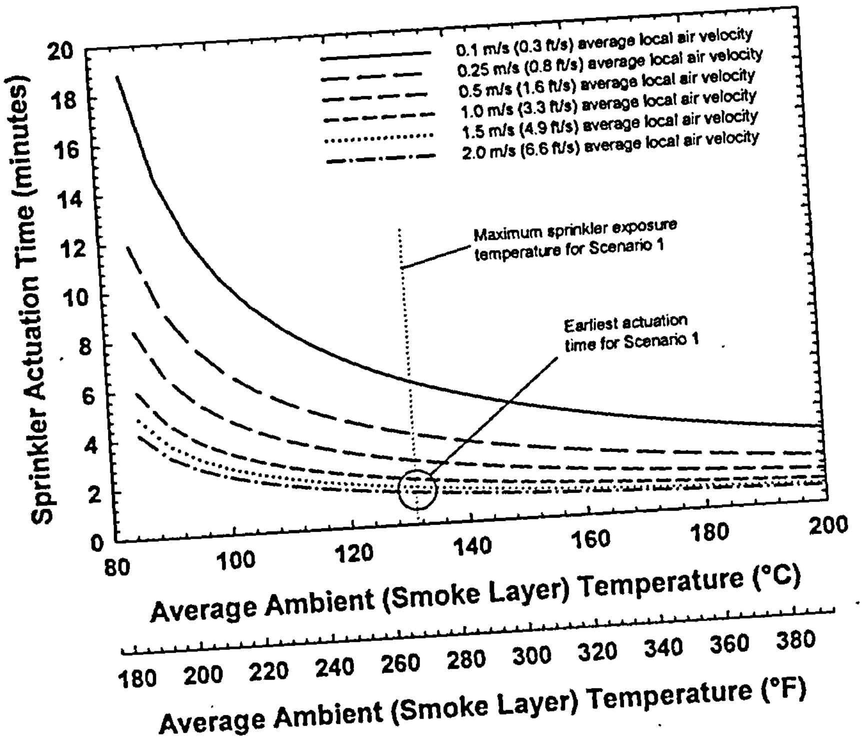


Figure A–9. Sprinkler Actuation Potential for Scenario 1

Sensitivity

The sensitivity of the results to assumptions regarding the composition of the transient fuel package and the ventilation conditions in the SWIS is examined in this section. In particular, the following aspects are considered:

- A transient fuel package that includes oil-soaked Class A material.
- The impact of opening the doors.
- The impact of the exhaust system located above the service water pumps.

<u>Oil-Soaked Class A Material – Room-wide Fire Exposure Potential</u>

The impact of the oil-soak transient Class A fuel package fire scenarios on the smoke layer development in the SWIS was evaluated using CFAST. Section A.7 contains a template input file for this calculation. The smoke layer temperature as a function of time is shown in Figure A–10 and the smoke layer elevation as a function of time is shown in Figure A–11 for transient fuel package heat release rates ranging from 350 kW – 1,500 kW (330 – 1,420 Btu/s). The results indicate that the increase peak heat release rate would not produce a smoke layer that immerses the thermoset and thermoplastic cable targets in the northeast corner greater than about 168°C (334°F).

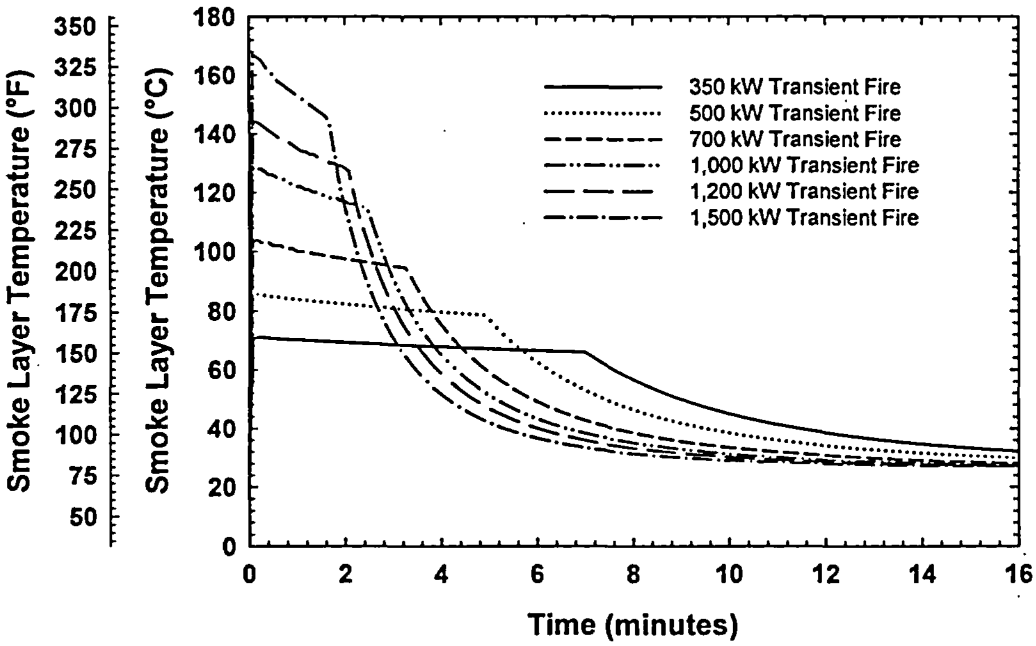


Figure A-10. Smoke Layer Temperature in the SWIS for Oil-Soaked Class A Transient Fuel Packages

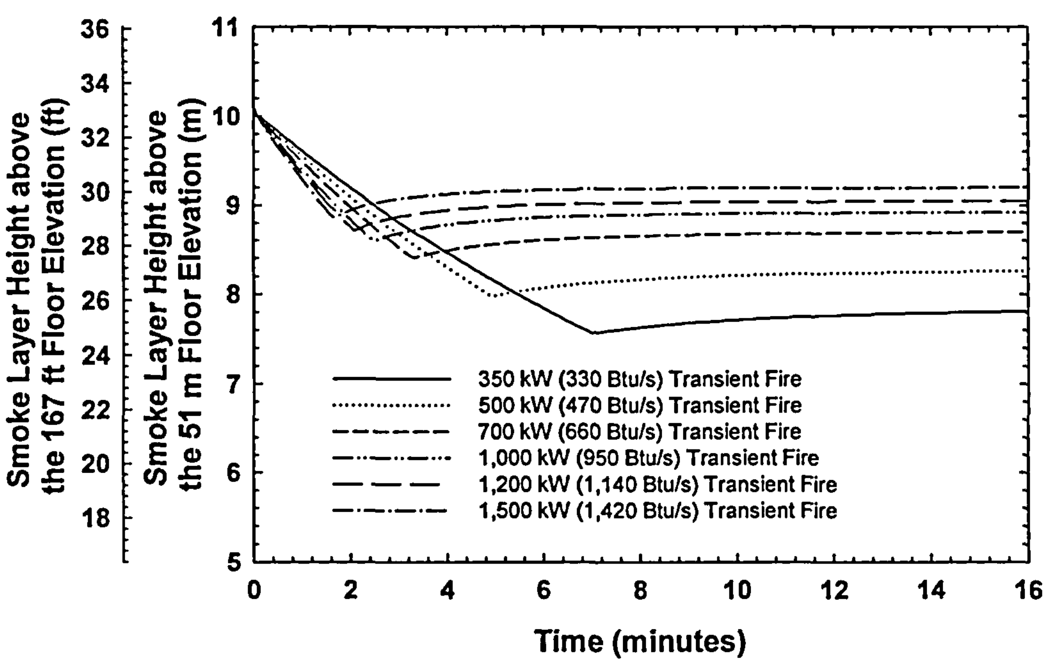


Figure A-11. Smoke Layer Elevation in the SWIS for Oil-Soaked Class A Transient Fuel Packages

Oil-Soaked Class A Material – Localized Fire Exposure Potential

A transient fuel package with oil-soaked Class A material is assumed to contain the same quantity of combustibles as available for combustion as described in Section A.3.1.1, namely 6.2 kg (13 lb). Section A.4.1 examines the impact of increasing the mass of the fuel package via the Limiting Fire Scenario (LFS). Oil-soaked Class A material is usually considered an ignition source [Gray, 2002]. However, there is the possibility that once ignited, the fuel package would exhibit an enhanced growth rate and an increased peak heat release rate when compared to a similar fuel package that is not oil-soaked. The growth rate for the transient fuel package summarized in Section A.3.1.1 is nearly instant (1 second); thus, an oil-soaked Class A fuel package would differ from the assumed fuel package in terms of the peak heat release rate and fire duration.

Table A–4 summarizes the maximum localized exposure conditions 6.1 m (20 ft) above the 51 m (167 ft) floor elevation in the northeast corner, the location of the Train A target cable trays (thermoset target) for peak heat release rates up to three-times the value assumed for the transient Class A fuel package. The table indicates that a peak heat release rate that is about three times greater than that assumed could result in an exposure temperature of 330°C (625°F). However, the fire duration is considerably shorter, less than three minutes.

Table A–5 summarizes the maximum localized exposure conditions 10.9 m (36 ft) above the 51 m (167 ft) floor elevation in the northeast corner, the location of the Train B target cable trays (thermoplastic target) for peak heat release rates up to three-times the value assumed for the transient Class A fuel package. The table indicates that a peak heat release rate that is about 3.4 times greater than that assumed could result in an exposure temperature of 263°C (505°F). However, the fire duration is considerably shorter, less than three minutes.

A conservative calculation of the cable surface temperature assuming immersion in the peak temperature was conducted using HEATING version 7.3. Appendix A.8 contains a detailed description of HEATING and provides a template file for this calculation. The duration of the exposure varies with the heat release rate as shown in Tables A–4 and A–5. A 0.6 mm thick (24 ga.) cable tray is assumed; an adiabatic boundary condition is applied to the interior of the cable jacket, conservatively ignoring the thermal capacitance of the copper core(s). The results are summarized in Tables A–4 and A–5 also. Based on these results, a heat release rate four times the peak heat release rate assumed would not cause the Train A cable jacket insulation to heat to 330°C (625°F). Likewise, a fire would not heat the Train B cable jacket insulation to 263°C (505°C), with a greater margin of safety than the Train A cable targets. This result is consistent with the tables in Attachment 7 of the SDP [NRC, 2004] and the calculation methodology summarized in NUREG 1805 for cable heating [NUREG 1805, 2003]. This heat release rate is expected to bound the oil-soaked Class A combustibles in terms of the increased peak heat release rate since the effective unit heat release rate would be greater than 4,000 kW/m^2 (352 Btu/s-ft^2), significantly greater than most types of materials [Babrauskas, 2002; Babrauskas, 2003]. Therefore, an oil-soaked Class A transient fuel package would not exceed the assumptions and conclusions of this analysis in terms of a localized exposure to the northeast corner target.

Table A–4. Localized Exposure Conditions at Train A Thermoset Cable Tray Target for Oil Soaked Transient Fire in the NE Corner of the SWIS

Peak Fire Size (kW [Btu/s])[1]	Fire Duration (s)	Flame Height (m [ft])	Peak Target Exposure Temperature (°C [°F)	Maximum Target Surface Temperature (°C [°F])
350 (330)	419	1.9 (6.2)	138 (280)	96 (205)
500 (470)	294	2.5 (8.2)	177 (351)	106 (223)
700 (660)	196	3.1 (10.2)	233 (451)	116 (241)
1,000 (950)	149	3.9 (12.8)	329 (624)	154 (309)
1,050 (1,000)	140	4.0 (13.1)	348 (658)	162 (324)
1,100 (1,040)	134	1.2 (3.9)	366 (691)	170 (338)
1,200 (1,140)	123	4.4 (14.4)	405 (761)	189 (372)
1,300 (1,230)	113	4.7 (15.4)	445 (833)	210 (410)
1,400 (1,330)	105	4.9 (16.1)	491 (916)	238 (460)
1,500 (1,420)	98	5.1 (16.7)	541 (1,006)	272 (522)

[1]Constant heat release rate

Table A–5. Localized Exposure Conditions at Train B Thermoplastic Cable Tray Target for Oil Soaked Transient Fire in the NE Corner of the SWIS

Peak Fire Size (kW [Btu/s])[1]	Fire Duration (s)	Peak Ambient Temperature (°C [°F)	Peak Target Exposure Temperature (°C [°F)	Maximum Target Surface Temperature (°C [°F])
350 (330)	419	70 (158)	114 (237)	< 263 (505)
500 (470)	294	85 (185)	142 (288)	< 263 (505)
700 (660)	196	105 (221)	180 (356)	< 263 (505)
1,000 (950)	149	129 (264)	232 (450)	< 263 (505)
1,050 (1,000)	140	133 (271)	241 (466)	< 263 (505)
1,100 (1,040)	134	136 (277)	249 (480)	< 263 (505)
1,200 (1,140)	123	144 (291)	267 (513)	107 (225)
1,300 (1,230)	113	152 (306)	285 (545)	111 (232)
1,400 (1,330)	105	160 (320)	304 (579)	115 (239)
1,500 (1,420)	98	168 (334)	324 (615)	121 (250)

[1]Constant heat release rate

SWIS Ventilation Conditions

The baseline ventilation conditions in the SWIS assume that the doors to adjacent areas are shut and that the mechanical exhaust fans above the service water pumps are not operating. The impact of the baseline assumptions on the development of the smoke layer in the SWIS is determined by modeling the following scenarios with CFAST:

- One door open to Fire Zone 72D or Fire Zone 72E.
- One door open to Fire Zone 72D and one door open to Fire Zone 72E.
- Mechanical exhaust fans for pumps associated with one unit operating.
- Mechanical exhaust fans for pumps associated with two units operating.
- Mechanical exhaust fans for one unit operating and one door open to Fire Zone 72D or Fire Zone 72E.

- Mechanical exhaust fans for two units operating and one door open to Fire Zone 72D and one door open to Fire Zone 72E.

The source fire in all cases is the transient Class A fuel package with a heat release rate profile as shown in Figure A–4. Section A.7 contains a master input file for the six alternate ventilation scenarios. Figures A–12 and A–13 show the smoke layer temperature and elevation in the SWIS for the baseline case and the six alternate ventilation scenarios. The figures indicate that the doors have little effect on the resulting temperature and smoke layer position in the SWIS. Also, the exhaust fans have a sufficient flow rate so as to prevent the buildup of a significant smoke layer for a transient corner fire. Although Figure A–13 indicates that the smoke layer elevation is near the ceiling, the model does not account for the beam pockets. A smoke layer with a thickness slightly greater than the maximum beam pocket depth would likely form, though this would not impact the overall results or conclusions since detection and suppression are not directly considered and there is a negligible temperature change from scenario to scenario.

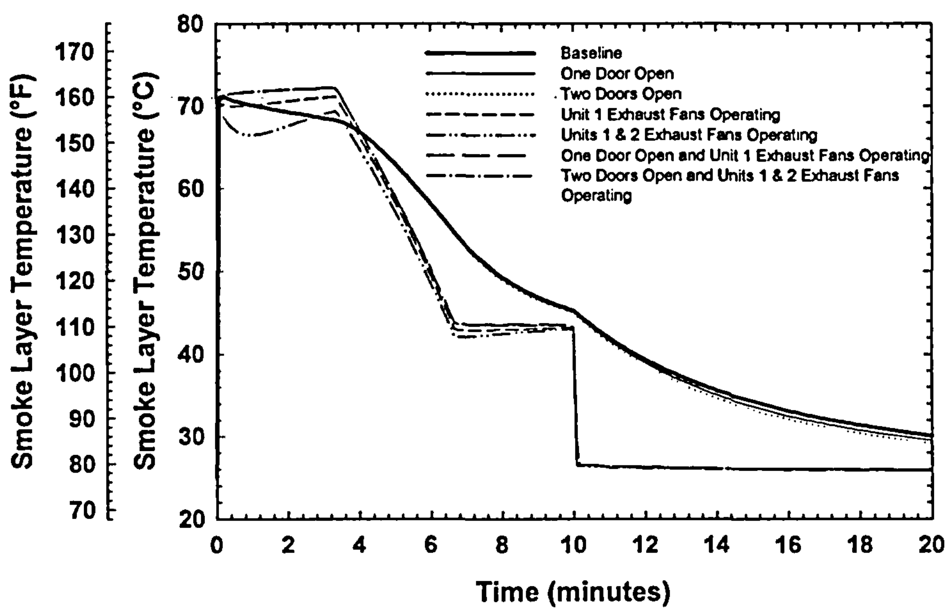


Figure A–12. Sensitivity of the Smoke Layer Temperature in the SWIS to Various Ventilation Conditions for a Transient Fire in the Northeast Corner

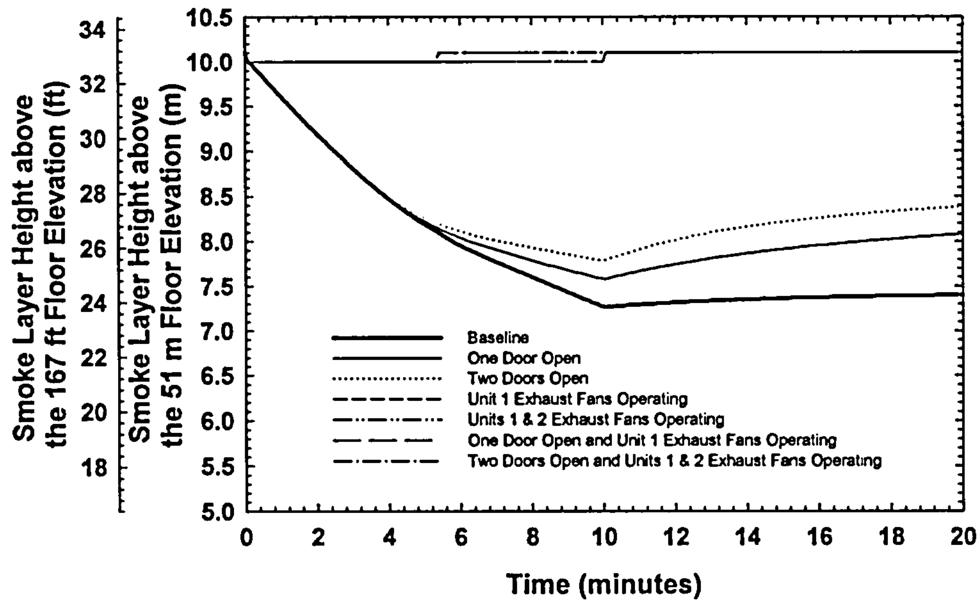


Figure A–13. Sensitivity of the Smoke Layer Elevation in the SWIS to Various Ventilation Conditions for a Transient Fire in the Northeast Corner

Conclusions

The following conclusions apply to the Class A combustible material fire scenario in the northeast corner of the SWIS on the Strainer Pit elevation:

- The maximum target exposure temperature to the Train A cable tray targets would be between 70°C (158°F) and 131°C (268°F), depending on where the fuel package is located;
- The maximum target exposure temperature to the Train B thermoplastic cable tray targets (additional fuel source) would be between 70°C (158°F) and 101°C (212°F), depending on where the fuel package is located;
- There would be no significant radiant exposure to targets located in the SWIS;
- Sprinklers could actuate in a little as one-two minutes; however, it is also possible that they would not actuate; and
- The SWIS targets would not be adversely impacted by this fire scenario.
- A sensitivity assessment of the ventilation conditions and fuel package composition indicates that the conclusions would not be impacted if the fuel package contained oil-soaked Class A material; if the doors are open to an adjacent area; or if the mechanical exhaust system above the service water pumps actuates.

A.3.2.3 Scenario 2

Scenario 2 is a lubricant pool fire that is located between the Unit 1 Service Water pumps and the south wall of the SWIS. Scenario 2A involves lubricant that originates from the Unit 1 C–Pump and remains within the curb area behind the C–Pump. Scenario 2B involves lubricant that originates from the Unit 1 E–Pumps and pools south and east of the E–Pump to the future curb between the south wall and radiant shield.

Targets

There are two targets that would be impacted by localized fire exposure. The targets are the pumps (motor junction boxes) and the A–Train cable tray near the east wall of the SWIS. Adjacent pumps are collectively a target when four or more pumps are impacted by the fire, as described in Section A.2.1.

The remaining targets in the SWIS would only be impacted by Scenarios 2A or 2B if the smoke layer temperature exceeded 500°C (932°F) (i.e., flashover); or if the smoke layer temperature exceeded 330°C (625°F) and the target were immersed in the smoke layer.

Smoke Layer Calculations

The smoke layer elevation and temperature in the SWIS for Scenarios 2A and 2B were calculated using CFAST [Jones et al., 2000]. The heat release rate for these fire scenarios is described in Section 3.2.2 and shown in Figure A–5. Section A.7 contains a description of the input parameters for the model. Note that the ceiling elevation above the Pump Deck is conservatively assumed to be 3.4 m (11 ft) to due to the ductwork and other obstructions. The results are shown in Figure A–14 (smoke layer temperature) and Figure A–15 (smoke layer elevation).

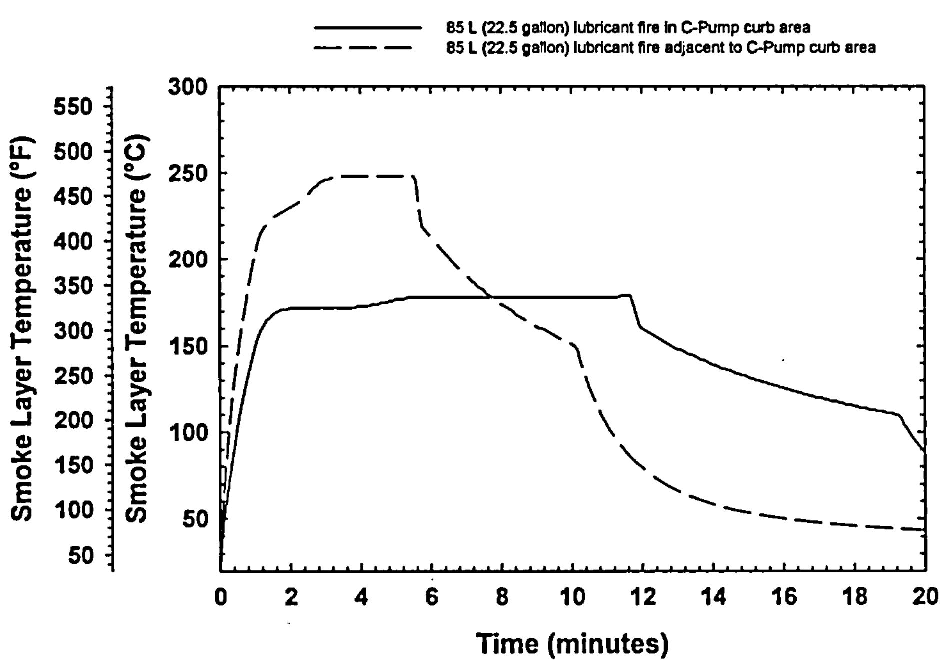


Figure A–14. Smoke Layer Temperature In Fire Area 72A - Unit 1 Pump Lubricant Fire Scenario

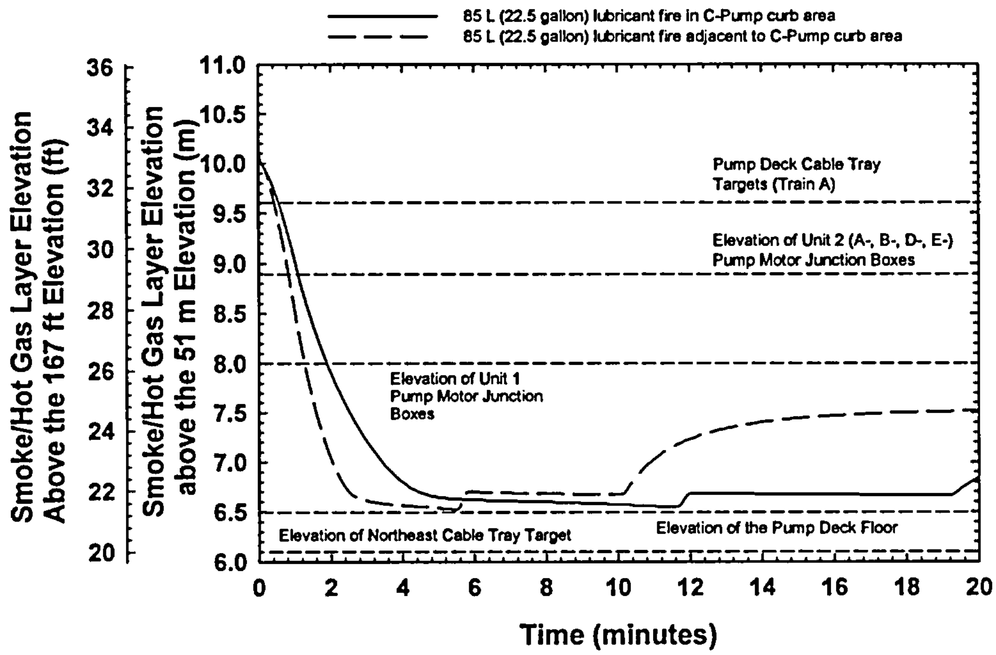


Figure A–15. Smoke Layer Elevation in Fire Area 72A – Unit 1 Pump Lubricant Fire Scenario

Figure A–15 indicates that local targets on the Pump Deck would be immersed by the smoke layer between 1 and 2 minutes after ignition. Figure A–14 shows that the calculated maximum temperature of the smoke layer is between 185°C (365°F) and 250°C (482°F) and that the average smoke layer temperature is around 170°C (338°F) and 230°C (446°F), below the critical temperature of 330°C (625°F) for thermoset cables and the auto-ignition temperature of 263°C (505°F) for thermoplastic cable jacket/insulation material. Thus, the smoke layer alone would not adversely affect targets located in Fire Area 72A of the SWIS.

It is possible that the smoke layer temperature is locally greater than that predicted by CFAST. Portions of the ceiling above the Pump Deck are isolated from other sections by the concrete beams thus forming bay-like sub regions. Combustion products that collect within bay-like areas of the ceiling would be less diluted and potentially hotter than would otherwise be the case. This effect would only be of concern if there were targets located within the bay-like areas or detector actuation were a consideration. Because there are no such targets and detection is not directly credited for these scenarios, these effects are not considered in this evaluation.

Localized Target Exposure

There are two targets that could be exposed directly by the fire, either via thermal radiation or flame impingement. These are:

- Pump motor junction boxes; and
- Train A cable tray near the east wall of the SWIS.

The above targets would be impacted by a lubricant fire via thermal radiation or a combination of thermal radiation and immersion in the smoke layer. There are no targets that would be susceptible to direct flame impingement conditions, except for pump motor junction boxes located within the area where the fire pools (i.e., A– and B–Pump motor junction boxes or D– and E–Pump motor junction boxes, or the C–Pump motor junction box).

The surface exposure conditions are described below.

Source Fire Emissive Power

The emissive power of the source fire is conservatively calculated as follows [Society of Fire Protection Engineers (SFPE), 1999]:

$$E = 58\left(10^{-0.00823D}\right) \qquad \text{(A–16)}$$

where E is the emissive power of luminous portions of the flame (kW/m² [Btu/s-ft²]) and D is the diameter of the source fire (m [ft]). A safety factor of two is recommended by the SFPE [1999] when using this approach in a conservative manner and clearly bounds the measured data upon which the correlation is based [Shokri et al., 1989; SFPE, 1999]. Accordingly, a safety factor of two is applied to the emissive power calculated using Equation A–16.

The emissive power for the Unit 1 pump fire scenarios may be calculated using the diameter listed in Table A–2 and Equation A–16. The results are as follows:

- Scenario 2A (C–Pump lubricant spill fire): 112.5 kW/m² (9.9 Btu/s-ft²); and
- Scenario 2B (E–Pump lubricant spill fire): 111.3 kW/m² (9.8 Btu/s-ft²).

Scenario 2B is used to evaluate the impact of an A–, B–, and D–Pump lubricant spill fire on adjacent pumps as previously described.

Note that the emissive power fluxes assumed include a safety factor of two and exceed maximum *flame impingement* heat fluxes as measured in full-scale fire tests for many configurations [Latimer, 2002]. This indicates that the results of the evaluation based on these values are very conservative in the absence of flame impingement.

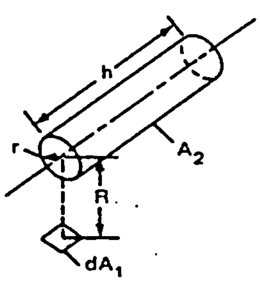
Target Incident Thermal Radiation – Smoke Layer Effects Ignored

The thermal radiation incident on a target in the absence of a smoke layer is a function of the emissive power of the source fire and the fraction of thermal radiation incident on the target originating from the source fire (configuration factor). This condition may arise if the exhaust fans above the pumps removed the smoke or if there were significant openings present that were not considered in the compartment fire model. The following equation describes this relationship [SFPE, 1999; Beyler, 2002a]:

$$\dot{q}_t'' = FE \qquad \text{(A–17)}$$

where q_i'' is the incident thermal radiation at the surface of a target (kW/m² [Btu/s-ft²]), F is the configuration factor between the target and the source fire, and E is the emissive power of the source fire (kW/m² [Btu/s-ft²]).

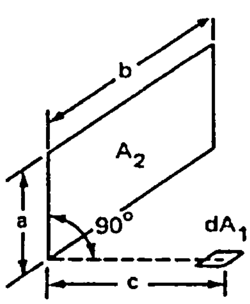
The configuration factor is a geometric relation that depends on the assumed shape of the fire, the location of the target relative to the fire, and the orientation of the target relative to the fire [SFPE, 1999; Tien et al., 2002; Howell, 1982]. Typically, a cylindrical fire shape is assumed, with a diameter equal to the effective diameter and a height equal to the flame height. In some instances, other configurations are more appropriate, such as where a radiation shield obstructs portions of the fire or delimits the area that radiates to a target. The latter case occurs when a lubricant fire exposes adjacent pump motor boxes because of the existing radiant heat shields between the Unit 1 C–Pump and the adjacent B–Pump and D–Pump. The three radiation configuration factors that are used in this evaluation are shown in Figures A–16a, A–16b, and A–16c [Tien et al., 2002].



$$L = h/r, \quad H = R/r, \quad X = (1 + H)^2 + L^2, \quad Y = (1 - H)^2 + L^2$$

$$F_{d1-2} = \frac{1}{\pi H} \tan^{-1}\left[\frac{L}{\sqrt{H^2-1}}\right] + \frac{L}{\pi}\left\{\frac{X-2H}{H\sqrt{XY}} \tan^{-1}\sqrt{\frac{X(H-1)}{Y(H+1)}} - \frac{1}{H}\tan^{-1}\sqrt{\frac{H-1}{H+1}}\right\}$$

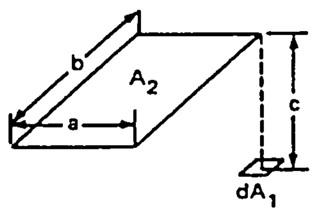
Figure A–16a. Maximum Configuration Factor between a Cylinder Emitter and a Target Surface



$$X = a/b, \quad Y = c/b, \quad A = 1/\sqrt{X^2 + Y^2}$$

$$F_{d1-2} = \frac{1}{2\pi}\{\tan^{-1}(1/Y) - AY\tan^{-1}A\}$$

Figure A–16b. Configuration Factor between a Rectangular Emitter and a Perpendicular Target Surface



$X = a/c, \quad Y = b/c$

$$F_{d1-2} = \frac{1}{2\pi}\left\{\frac{X}{\sqrt{1+X^2}}\tan^{-1}\left[\frac{Y}{\sqrt{1+X^2}}\right] + \frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\left[\frac{X}{\sqrt{1+Y^2}}\right]\right\}$$

Figure A–16c. Configuration Factor between a Rectangular Emitter and a Parallel Target Surface

The configuration factor summarized in Figure A–16a is used when there are no obstructions assumed between the target and the source fire. The configuration factors shown in Figures A–16b and A–16c are used when there are significant obstructions between the source fire and target, in particular a radiant heat shield, overhead cable trays, and concrete beams. Field surveys found that in the area south of the Service Water pumps, flame portions greater than 3 m (10 ft) above the pump deck floor would be completely obstructed from targets below 3 m (10 ft).

Table A–2, Figure A–2, and Figures A–16a through A–16c were used to calculate the configuration factor between a Unit 1 pump lubricant fire and the local targets. The incident heat flux was calculated using Equations A–16 and A–17. The results are shown in Table A–6. Note that the Train A cable tray target exposure is bounded by a fire that involves a Unit 1 E–Pump lubricant spill. Also, adjacent pump fire exposures for A–, B–, D–, and E–Pumps assume that the E–Pump lubricant spill is adjacent the C-Pump curb.

When calculating the incident heat flux to an adjacent pump motor junction box, the results are presented in terms of a parallel surface and a perpendicular surface because of the fixed orientation of the junction boxes relative to the fire location. The significance of this will be evident in the next section.

Table A–6. Configuration Factor and Target Flux for Unit 1 Pump Lubricant Fire Scenarios

Scenario	Target	Configuration Factor, F	Incident Target Flux, $\dot{q}''_t$ (kW/m² [Btu/s-ft²])
Unit 1 C-Pump Lubricant Fire (Scenario 2A)	Train A Cable Tray	Not Calculated – Bounded by D or E Lubricant Fire	
	Adjacent Pump	0.4 [parallel surface] 0.23 [perpendicular surface]	45.0 (4.0) [parallel surface] 25.9 (2.3) [perpendicular surface]
	Pump beyond adjacent pump (2nd tier pump)	0.17 [parallel surface] 0.045 [perpendicular surface]	19.1 (1.7) [parallel surface] 5.1 (0.45) [perpendicular surface]
Unit 1 A-, B-, D- or E- Pump Lubricant Fire (Scenario 2B)	Train A Cable Tray (E-Pump Fire Only)	0.141 [parallel surface]	15.7 (1.4) [parallel surface]
	Adjacent Pump	0.39 [parallel surface] 0.22 [perpendicular surface]	44.5 (3.9) [parallel surface] 25.6 (2.3) [perpendicular surface]
	Pump beyond adjacent pump (2nd tier pump)	0.16 [parallel surface] 0.044 [perpendicular surface]	18.9 (1.7) [parallel surface] 5.0 (0.44) [perpendicular surface]

Table A–6 indicates that the incident flux exceeds the critical flux of 11.4 kW/m² (1.0 Btu/s-ft²) in all cases, except for perpendicular surfaces of second tier pump motor box targets. The incident heat flux to adjacent pump motor boxes may be as high as 45 kW/m² (4.0 Btu/s-ft²), which is significantly greater than the critical flux. As a result, pumps adjacent to pump where a fire originates or where the fire is burning and pumps adjacent to those could be adversely damaged by the fire if the postulated fire exposure were maintained sufficiently long. A thermal evaluation is therefore necessary to determine which pumps, besides the pump where the fire originates, could be damaged by the postulated fire exposure.

Figure A–15 indicates that the smoke layer would immerse the Train A cable trays and the Unit 2 pump motor junction boxes in less than a minute and the Unit 1 pump motor junction boxes in less than two minutes, depending on the particular pump lubricant fire scenario. The temperature of the smoke layer after it immerses the targets would be between 185 – 250°C (365–482°F). As previously noted, this temperature is below the critical cable temperature of 330°C (625°F). Thus, a thermal evaluation of the targets involves a combined smoke layer immersion–thermal radiation exposure boundary condition.

Combined Smoke Layer Immersion–Thermal Radiation Exposure

A combined smoke layer immersion–thermal radiation exposure involves a convective and/or radiant exposure component from the smoke layer plus a radiant heat flux component directly from the flames. There are two phases to the exposure: before and after smoke layer immersion.

- Pre-smoke layer immersion exposure

  The smoke layer only exposes the target to a radiant heat flux during this phase. This may be estimated using the following equation [Tien et al., 2002]:

  $$\dot{q}''_{L,r} = \alpha_t \varepsilon \sigma F T_L^4 \qquad \text{(A–18)}$$

  where $\dot{q}''_{L,r}$ is the maximum incident heat flux at the target surface that originates from the smoke layer (kW/m² [Btu/s-ft²]), α_t is the absorbance of the target surface (0.8), ε is the smoke layer emissivity (1.0), σ is the Stefan-Boltzmann constant (5.669 x 10^{-11} kW/m²-K^4 [4.76 x 10^{-13} Btu/s-ft²-°R^4]), F is the view factor between the target surface and the smoke layer, and T_L is the smoke layer temperature (K [°R]). The maximum possible view factor between the smoke layer and a vertical target is 0.5; the maximum possible view factor between the smoke layer and a horizontal target is 1.0. The maximum smoke layer temperature calculated for either Scenario 2A or Scenario 2B is approximately 250°C (482°F). The maximum net heat flux at the surface of a vertical target is thus 1.7 kW/m² (0.15 Btu/s-ft²) and for a horizontal target, it is 3.4 kW/m² (0.3 Btu/s-ft²).

  The flames also expose the target to a radiant heat flux that varies with target location and orientation. This information is summarized in Table A–6.

- Post-smoke layer immersion exposure

The smoke layer exposes the target to a convection and radiation heat flux during this phase that is independent of target orientation. The convective component is a function of both the smoke layer temperature and the target surface temperature and is given by the following equation [Holman, 1990]:

$$\dot{q}''_{L,c} = 1.32(T_L - T_t)^{4/3} \qquad \text{(A–19)}$$

where $\dot{q}''_{L,c}$ is the convective heat flux from the layer to the target (kW/m² [Btu/s-ft²]) and T_t is the target surface temperature (K [°R]).

The radiant component from the smoke layer to the target is given by Equation A–18, with the view factor set to unity. The radiant component from the flames to the fire is a function of the target orientation and distance from the flames and is calculated using the following equation:

$$\dot{q}''_{F,r} = \alpha_L \dot{q}''_t \qquad \text{(A–20)}$$

where $\dot{q}''_{F,r}$ is the incident radiant heat flux at the surface of the target in the presence of a smoke layer (kW/m² [Btu/s-ft²]) and α_L is the fraction of radiant energy emitted by the flames and absorbed by the smoke layer between the flames and the target (the smoke layer absorbance).

The smoke layer absorbance may be estimated using the following equation assuming that fraction of radiation reflected or scattered by the layer is zero [Hoover et al., 2000]:

$$A_T = 1 - ([\exp(-\alpha_S C_S L)][1 - A_{H_2O} - 0.5A_{CO_2}]) \qquad \text{(A–21)}$$

where A_T is the total absorbance of the smoke layer over the distance L (m [ft]), α_S is the effective soot specific absorbance (m²/kg [ft²/lb]), C_S is the soot concentration (kg/m³ [lb/ft³]), A_{H_2O} is the absorbance of the water in the smoke layer, and A_{CO_2} is the absorbance of the carbon dioxide in the smoke layer. It is conservatively assumed that the absorbance of the water and carbon dioxide is zero. The soot absorbance constants may be estimated from the following equation [Tien et al., 2002; Hoover et al., 2000]:

$$\alpha_S C_S = k f_V T \qquad \text{(A–22)}$$

where k is a constant equal to 1,196 m^{-1} (365 ft^{-1}), f_V is the soot volume fraction, and T is the soot temperature (K [°R]). The soot volume fraction is related to the optical density (OD) parameter calculated by CFAST via the following equation [Jones et al., 2000; Seader et al., 1976]:

$$f_V = \frac{1}{\rho_S}\left(\frac{OD}{3500}\right) \qquad \text{(A–23)}$$

where ρ_S is the smoke density (1,800 kg/m³ [112 lb/ft³]), ρ_L is the density of the smoke layer (kg/m³ [lb/ft³]), and *OD* is the optical density as provided by CFAST.

The absorbance length (*L*) is assumed equal to the minimum path length through the smoke, which is equal to the minimum distance between the flames and the target once the layer reaches a critical depth given by the following geometric relation:

$$H_{cr} = T_h - S_m \cdot \cos\left(\tan^{-1}\left(S_m / T_h\right)\right) \qquad \text{(A–24)}$$

where H_{cr} is the critical smoke layer height above the pump deck floor (m [ft]) where the minimum absorbance length is equal to the minimum target separation distance S_m (m [ft]), and T_h is the target height above the pump deck floor (m [ft]). Pre-immersion exposure conditions are assumed prior to the smoke layer reaching the critical depth determined using Equation A–24.

Since the particulate concentration increases with time, the absorbance of the smoke layer also increases with time as the fire continues to burn. The smoke layer absorbance parameters are summarized in Table A–7 for the Train A cable tray and second tier pump motor junction box targets. Figures A–17 and A–18 shows the transient target heat flux determined using Equations A–20 through A–23 and the CFAST output data that was used in the thermal calculations for the C–Pump and A–, B–, D–, or E– Pump lubricant fires.

Table A–7. Smoke Absorbance Parameters for the Unit 1 Pump Lubricant Fire Scenarios

Scenario	Target	Minimum Target Distance (m [ft])	Target Elevation above the Pump Deck Floor (m [ft])	Critical Target Elevation Above the Pump Deck Floor (m [ft])	Time Smoke Layer Depth Reaches Critical Depth (min)
C–Pump Lubricant Fire	Train A Cable Tray	Bound by the E–Pump Fire Scenario			
	2nd Tier Motor Junction Box	2.3 (7.5)	1.5 (5)	1 (3)	2.4
A–, B–, D– or E– Pump Lubricant Fire	Train A Cable Tray (E-Pump Fire Only)	3.1 (10)	3.1 (10)	1 (3)	1.6
	2nd Tier Motor Junction Box	2.3 (7.5)	1.5 (5)	1 (3)	1.6

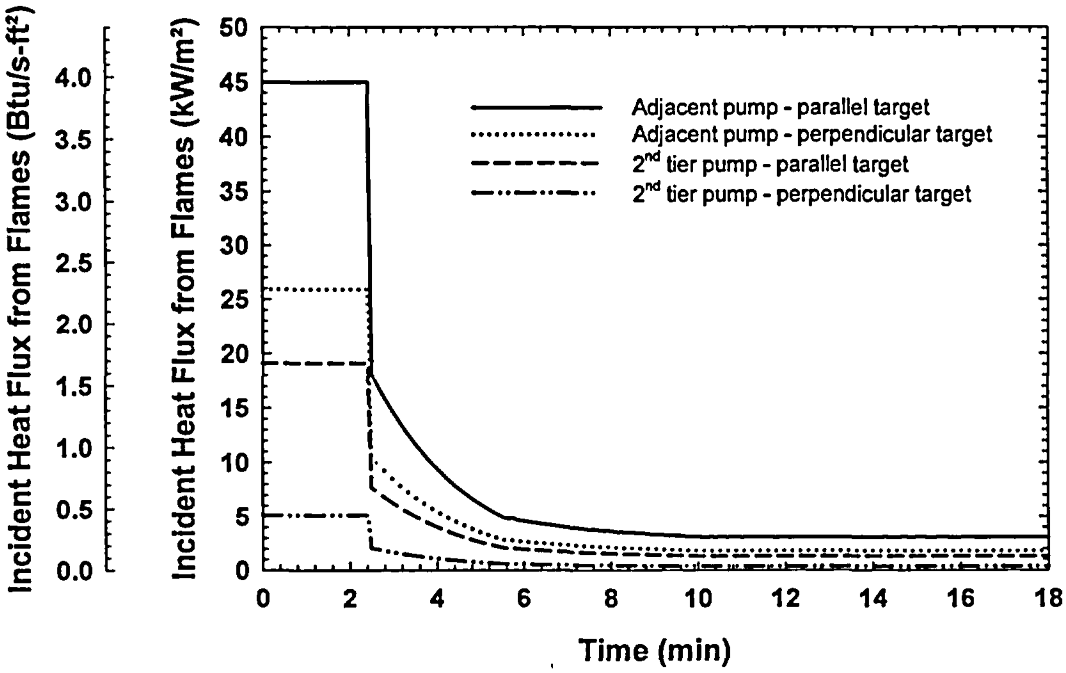


Figure A–17. Transient Target Heat Flux from Flames for C–Pump Lubricant Fire

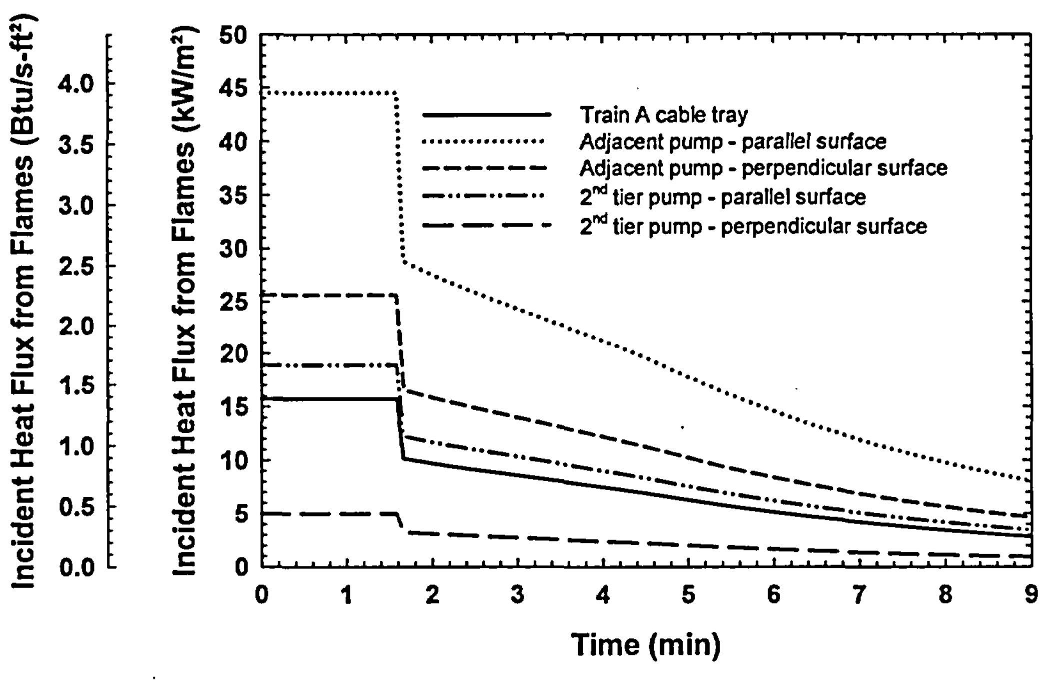


Figure A–18. Transient Target Heat Flux from Flames for A–, B–, D–, or E–Pump Lubricant Fires

Figures A–17 and A–18 indicate that once the layer reaches the critical depth, it will initially absorb about 35 – 40 percent of the flame radiation. When the lubricant is exhausted, the layer absorbs around 85 – 95 percent of the flame radiation. The most severe scenario within a given exposure set (i.e., those shown in Figure A–17 or A–18) is clearly the adjacent pump (parallel and perpendicular surfaces) followed by the second tier pump exposure. The most severe exposure between sets is not as obvious; the C–Pump fire exposure has a longer period where the smoke layer does not absorb flame radiation and a longer overall duration; however the smoke absorbance increases faster and the incident flux drops faster than the A–, B–, D–, or E–Pump fire exposure.

<u>Transient Thermal Analysis of Local Targets</u>

The response of the target surfaces to the pre- and post-immersion boundary conditions is examined for each scenario summarized in Table A–6 and shown in Figures A–17 and A–18 to identify which would result in the target exceeding the critical temperature of 330°C (625°F).

Two types of targets are considered: the A–Train cable tray and a pump motor junction box. HEATING7 version 7.3 was used to calculate the target surface temperature as a function of time given the heat flux exposure [Childs, 1998]. Section A.8 contains a complete description of HEATING7, the assumed input parameters, and the input files used in this analysis. Figures A-19a and A-19b show the configurations modeled. Dimensions of cables and the targets are based on information available for 1/C #2/0 PVC-PVC power cables [Ebasco, 1974] and field measurements of the targets.

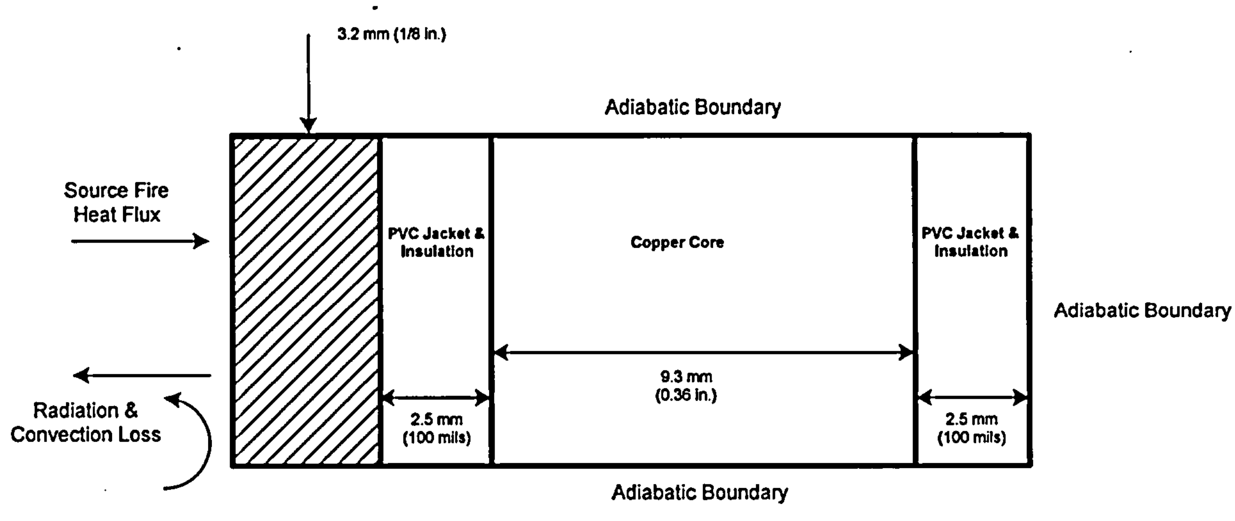


Figure A-19a. Train A Cable Tray Section Analyzed with HEATING7

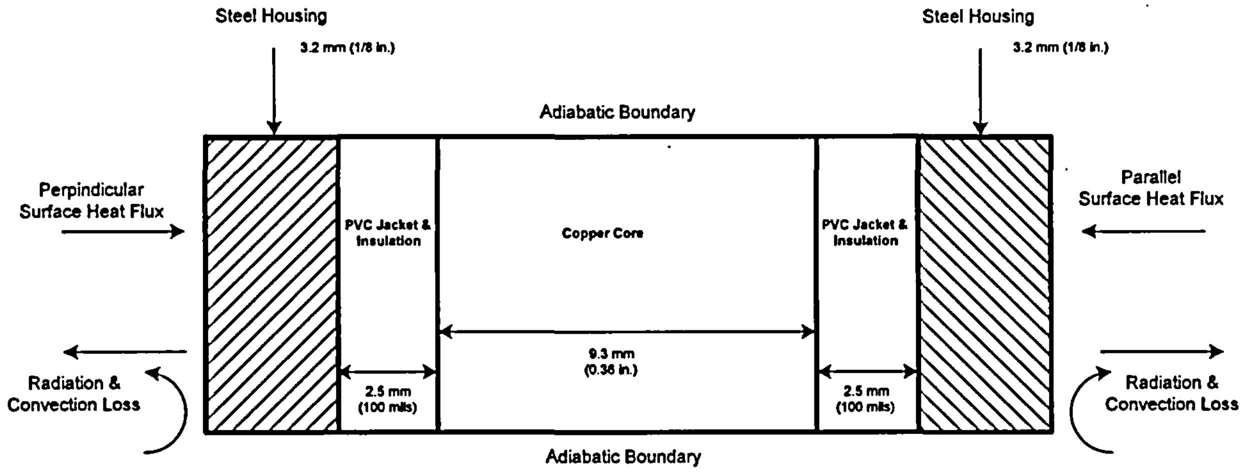


Figure A-19b. Second Tier Pump Motor Junction Box Analyzed with HEATING7 – Parallel and Perpendicular Target Orientations

The A–Train cable tray configuration depicted in Figure A–19a depicts the one-dimensional model used to calculate the surface temperature of the cable tray. A single 1/C #2/0 power cable was assumed adjacent to the side of the tray, typical for the area. This configuration is conservative because the peak heat flux is used as the exposure boundary condition and conduction losses into the steel tray and copper conductor along other planes is ignored. The unexposed surface of the cable was assumed adiabatic, also a conservative assumption since convection and conduction losses into other cables are ignored.

The pump motor junction box configuration depicted in Figure A–19b depicts the one-dimensional model used to calculate the surface temperature of the cables within the junction box. A single 1/C #2/0 power cable was assumed adjacent to the side of the tray, which is typical for the type of motors involved. This configuration applies to both the parallel and perpendicular configurations. A cable is assumed sandwiched between the motor junction box housing. Splice material is conservatively ignored as is conduction and convection losses within the junction box. The exposed boundary condition assumes either the parallel or perpendicular surface exposures; the unexposed is the perpendicular or parallel surface exposures, respectively. The result is therefore the same regardless which surface is assumed exposed with the maximum cable insulation temperature located on the side where parallel surface exposure boundary condition is applied.

Each of the C–Pump and A–, B–, D–, or E–Pump fire exposures were evaluated using HEATING. The boundary conditions are as previously described for pre- and post-smoke layer immersion. The following scenarios were evaluated:

- C–Pump Fire: adjacent pump and second tier pump targets; and
- A–, B–, D–, or E–Pump fire: A–Train cable tray; adjacent pump; and second tier pump targets.

The temperature results for the two scenarios and various targets are summarized in Figures A–20 and A–21.

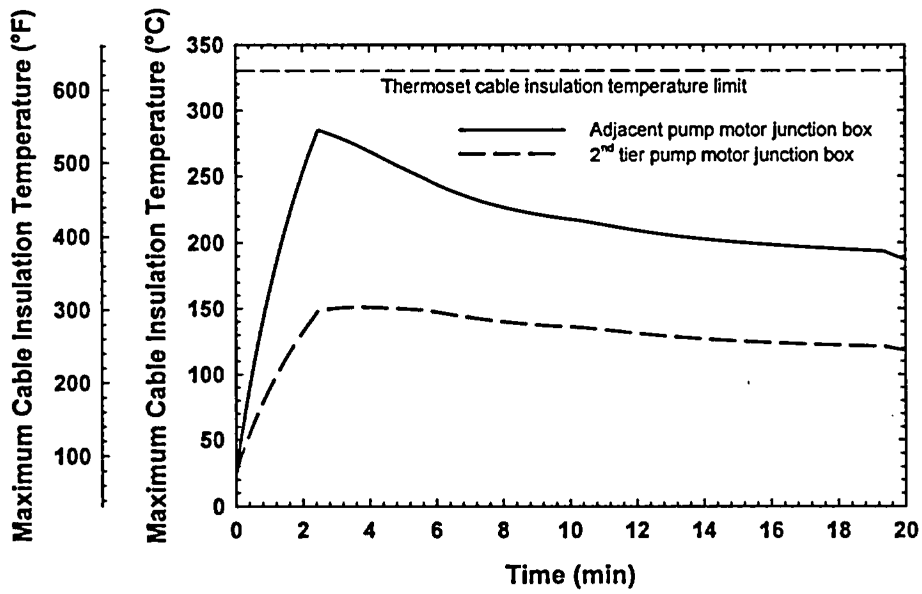


Figure A-20. Transient Target Surface Temperatures – Unit 1 C–Pump Lubricant Fire Scenario

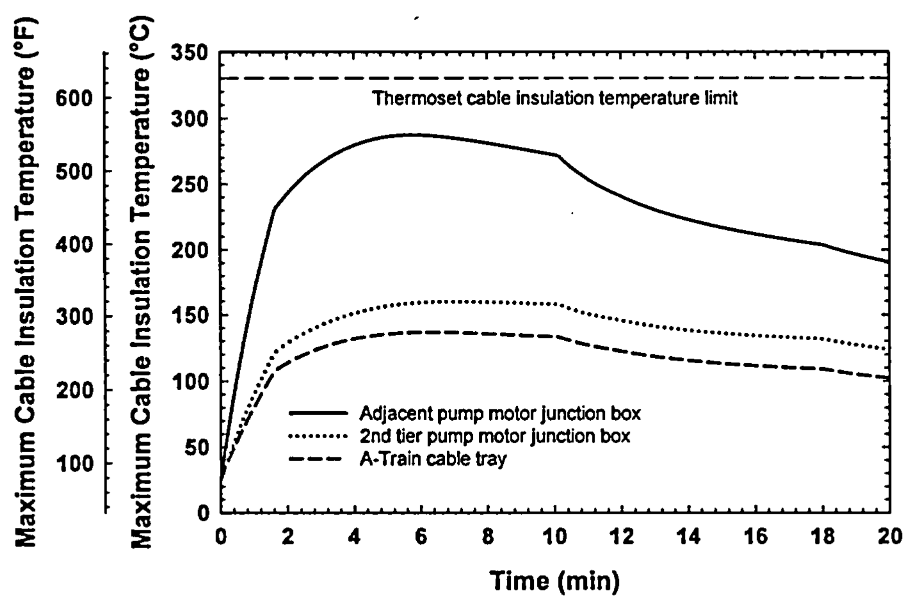


Figure A–21. Transient Target Surface Temperatures – Unit 1 A–, B–, D–, or E–Pump Lubricant Fire Scenarios

Figures A–20 and A–21 indicate that the postulated fire exposures would not cause the cable insulation temperature to exceed the critical value for adjacent exposed pump motor junction boxes, second tier (i.e., beyond adjacent) pump motor junction boxes, and for the A-Train cable tray. The most severe exposure involves the adjacent junction boxes, which may result in cable insulation temperatures around 300°C (572°F), about 30°C (54°F) below the critical value of 330°C (625°F). Note that the temperature increase for other targets other than adjacent pump motor junction boxes would be less than half that required to reach the critical temperature. Combined with the safety factor of two applied to the emissive power, the net safety factor is around four for these targets.

Unconfined Target Impact Zone

An unconfined target impact zone may be established as a means of screening other potential targets not identified in this analysis. Equation A–17 and the configuration factor shown in Figure A-16A may be solved for a target heat flux of 11.4 kW/m² (1.0 Btu/s-ft²), the critical value for all targets considered. The results are shown in Table A–8. Note that the calculation assumes there are no obstructions such, the flame height is equal to the ceiling height of 4.9 m (16 ft), and the target elevation is one-half the ceiling height. The impact of a possible flame extension beneath the ceiling is not included in results shown in Table A–8.

The damage thresholds are not applicable to areas beyond the Pump Deck in the SWIS. A larger fire than that assumed is also possible depending on the area where the liquid pools and the thickness of the pool. However, a larger source fire would not significantly increase the target heat flux but the duration of the fire would be reduced. The information in Table A–8 is only useful for identifying targets that are potentially impacted by the source fire. A detailed analysis may be necessary if additional targets are identified.

Table A–8. Target Impact Zone for Unit 1 Lubricant Fire Scenarios – No Obstructions

Scenario	Emissive Power (kW/m² [Btu/s-ft²])	Equivalent Fire Diameter (m [ft])	Target Damage Distance (m [ft])	
			From Fire Center	From Fire Edge
C-Pump Lubricant Fire	112.9 (9.9)	1.6 (5.2)	4.9 (16.1)	4.1 (13.4)
A-, B-, D-, or E-Pump Lubricant Fire	111.3 (9.8)	2.2 (7.3)	5.9 (19.4)	4.8 (15.8)

Suppression System Actuation

The Pump Deck is equipped with pre-action sprinklers with an actuation temperature of 79°C (175°F) [Drawing D-180986, 1983]. As noted in Section A.1.1.3, the assumed RTI for the sprinkler model installed in the SWIS is 155 $m^{1/2}$-$s^{1/2}$ (281 $ft^{1/2}$-$s^{1/2}$) based on information provided by the distributor [Fleenor, 2002].

Individual pumps are also equipped with a directional water spray pre-action system that uses horizontal heat collectors and sprinklers identical to the pre-action systems [Drawing D-170921, 1993].

The potential for the suppression systems to actuate was estimated using the temperature results of the smoke layer and the fire characteristics. Because the fire is expected to impinge on the ceiling, the most optimistic estimate of the sprinkler actuation time would be on the order of a minute or less especially considering that the concrete beams may confine the ceiling jet and create a locally hotter area above the fire. An upper bound on the sprinkler actuation time assumes that the nearest sprinkler is located in a separate bay under which the fire is located. In this case, the smoke layer would be the primary source of heating. Figure A–14 indicates that the average smoke layer temperature would be between 170°C (338°F) and 250°C (482°F) for Scenario 2A and Scenario 2B, respectively. Assuming a relatively stagnant layer results in an actuation time of approximately 3 – 4 minutes, as seen in Figure A–22. Refer to Section A.9 for a discussion of the sprinkler actuation calculations.

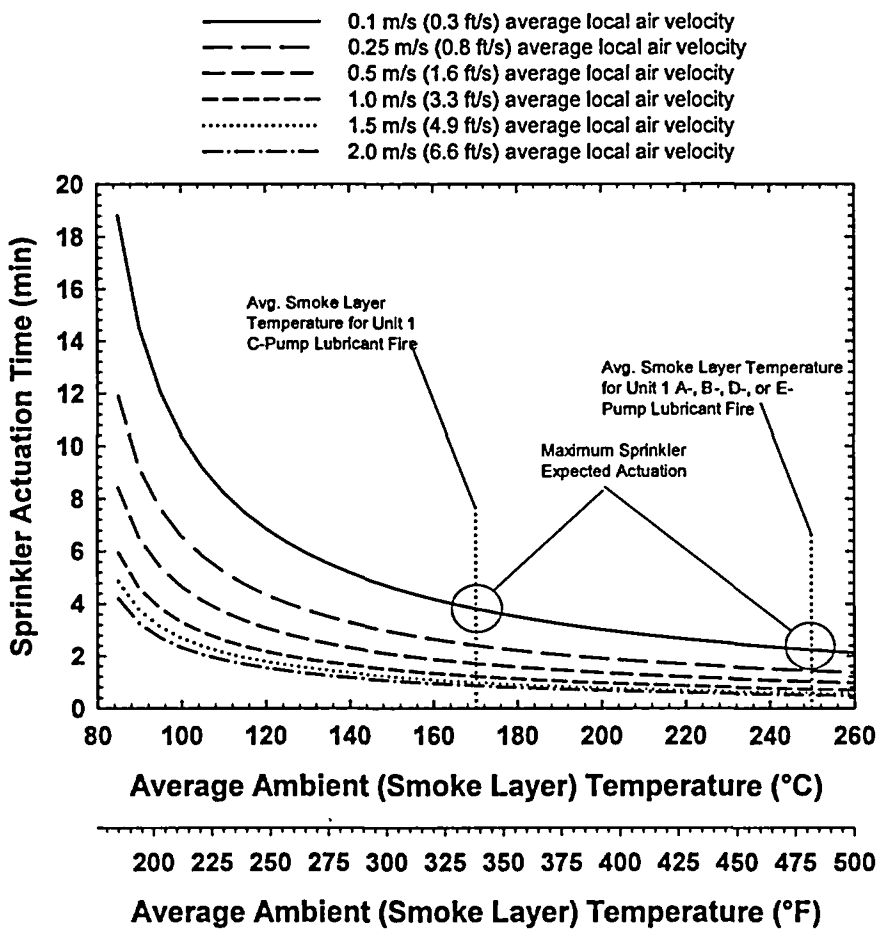


Figure A–22. Sprinkler Actuation Potential for Unit 1 Pump Fire Scenarios

Sensitivity

The sensitivity of the results to assumptions regarding the ventilation conditions and thermal aspects of the target were considered. In particular, the following were considered:

- The impact of opening the doors;
- The impact of the exhaust system located above the service water pumps; and
- Absorptance of target.

SWIS Ventilation Conditions

The baseline ventilation conditions in the SWIS assume that the doors to adjacent areas are shut and that the mechanical exhaust fans above the service water pumps are not operating. The impact of the baseline assumptions on the development of the smoke layer in the SWIS is determined by modeling the following scenarios with CFAST:

- One door open to Fire Zone 72D or Fire Zone 72E.
- One door open to Fire Zone 72D and one door open to Fire Zone 72E.
- Mechanical exhaust fans for pumps associated with one unit operating.
- Mechanical exhaust fans for pumps associated with two units operating.
- Mechanical exhaust fans for one unit operating and one door open to Fire Zone 72D or Fire Zone 72E.
- Mechanical exhaust fans for two units operating and one door open to Fire Zone 72D and one door open to Fire Zone 72E.

The source fire in all cases is the lubricant fire with a heat release rate profile as shown in Figure A–5. Section A.7 contains a master input file for the six alternate ventilation scenarios for the two pool fires considered. Figures A–23 through A–27 show the smoke layer elevation and temperature in the SWIS for the baseline case and the six alternate ventilation scenarios.

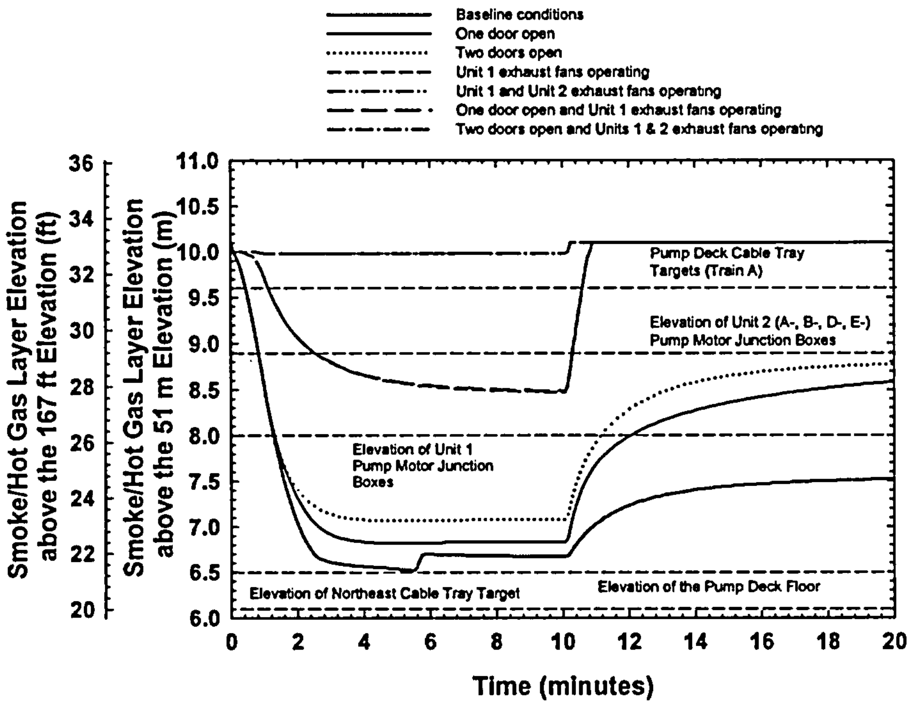


Figure A–23. Smoke Layer Elevation in the SWIS for Alternate Ventilation Conditions Unit 1 C–Pump Pool Fire Scenario

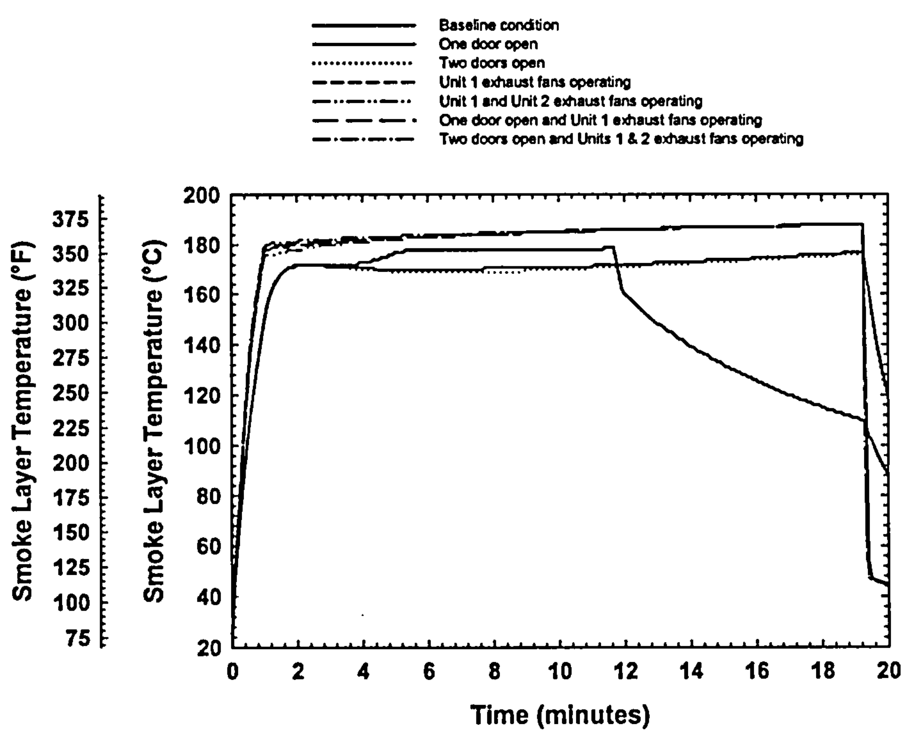


Figure A–24. Smoke Layer Temperature in the SWIS for Alternate Ventilation Conditions Unit 1 C–Pump Pool Fire Scenario

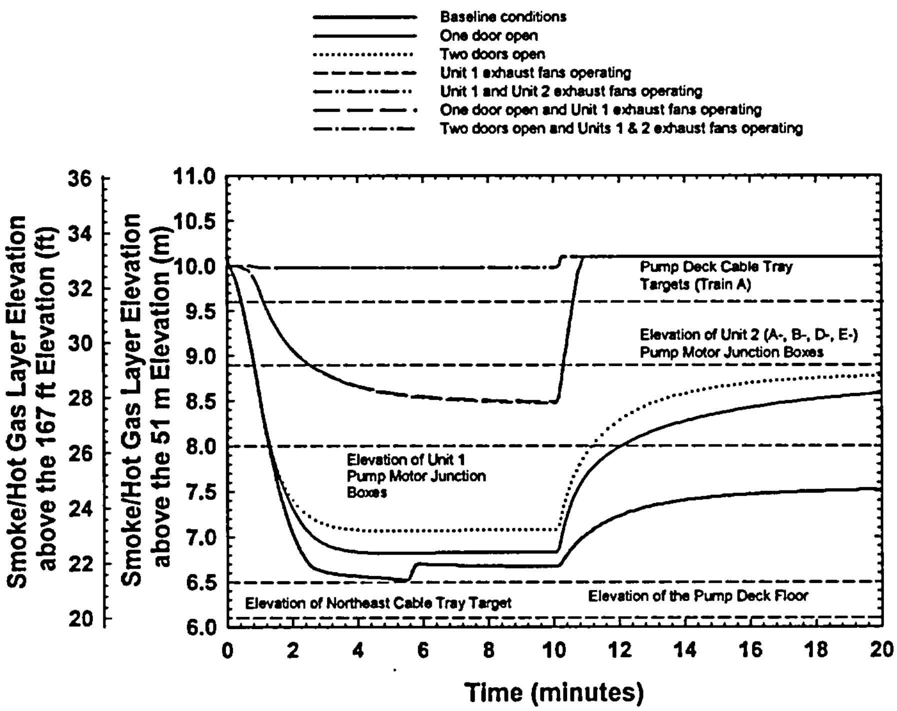


Figure A-25. Smoke Layer Elevation in the SWIS for Alternate Ventilation Conditions Unit 1 A-, B-, D-, or E-Pump Pool Fire Scenarios

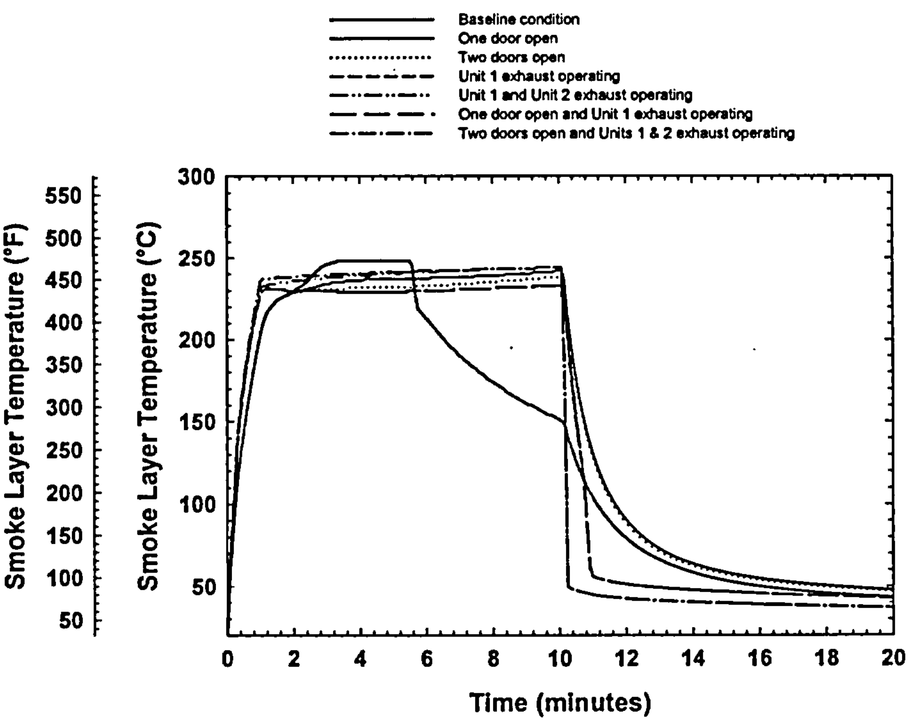


Figure A-26. Smoke Layer Elevation in the SWIS for Alternate Ventilation Conditions Unit 1 A-, B-, D-, or E-Pump Pool Fire Scenarios

Figures A–24 and A–26 indicate that if the doors to the SWIS are open and/or the Unit 1 or Unit 2 exhaust fans are operating, the temperature within the area would not be significantly impacted. Additionally, Figures A–23 and A–25 indicate that open doors would not significantly change the smoke layer position with time, though the steady state elevation would be somewhat higher than the baseline conditions. If the mechanical exhaust fans operate, there is the potential for the smoke layer to remain above the targets. This implies that the targets would be exposed to the thermal radiation from the source fire plus a radiant exposure from the smoke layer in the case of a pool fire associated with an A–, B–, D–, or E–Pump fire. The exhaust system is sufficient to maintain the smoke layer near the ceiling level for a C–Pump fire such that the radiant heat flux exposure would be insignificant.

A thermal evaluation is required to determine the maximum target temperature if the smoke layer remains above the target. The methodology described for the combined smoke layer immersion – thermal radiation exposure for the pre-layer immersion component is used. The smoke layer contribution is as follows:

- C-Pump fire scenarios: 0 kW/m^2 (0 $Btu/s\text{-}ft^2$). The smoke layer remains at the ceiling (Figure A–23) suggesting a configuration factor much less than unity for target surfaces parallel and perpendicular to the smoke layer. The resulting radiant heat flux contribution from the smoke layer is insignificant.
- A–, B–, D–, or E–Pump fire scenarios. The smoke layer may be located near the target, thus the view factors could approach unity for target surfaces parallel to the smoke layer and ½ for target surfaces perpendicular to the smoke layer. As such, the contribution from the layer is as determined for the MEFS: 1.7 kW/m^2 (0.15 $Btu/s\text{-}ft^2$) for target surfaces perpendicular to the smoke layer (and parallel to the flame surface) and 3.4 kW/m^2 (0.3 $Btu/s\text{-}ft^2$) for target surfaces parallel to the smoke layer (and perpendicular to the flame surface.

The heat flux from the fire is as shown in Table A–7. The results are shown in Figure A–27.

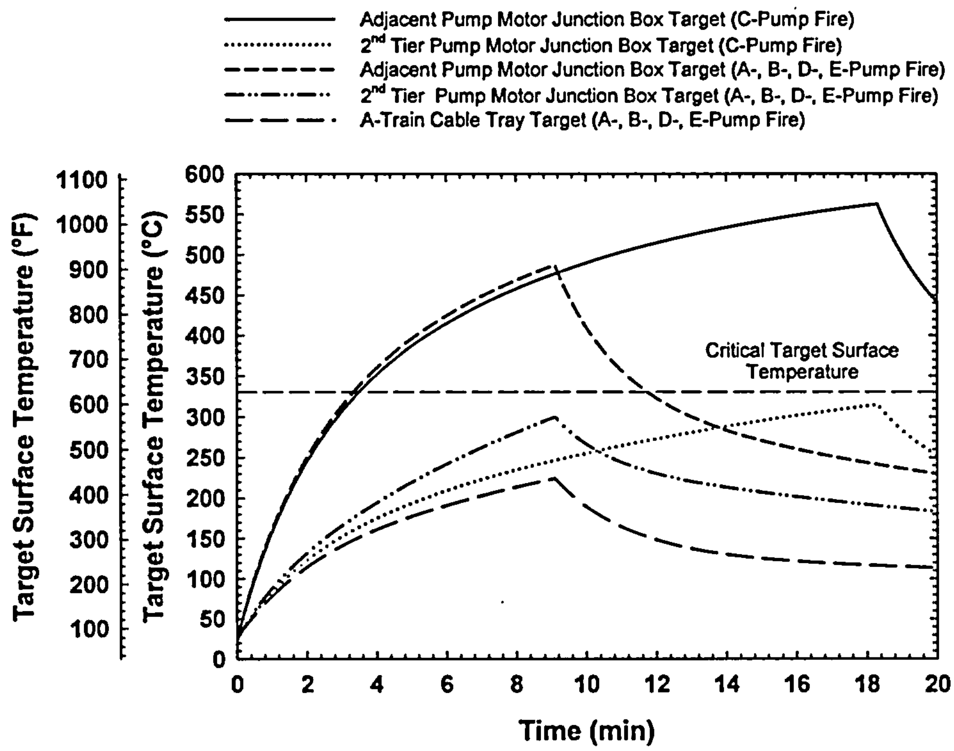
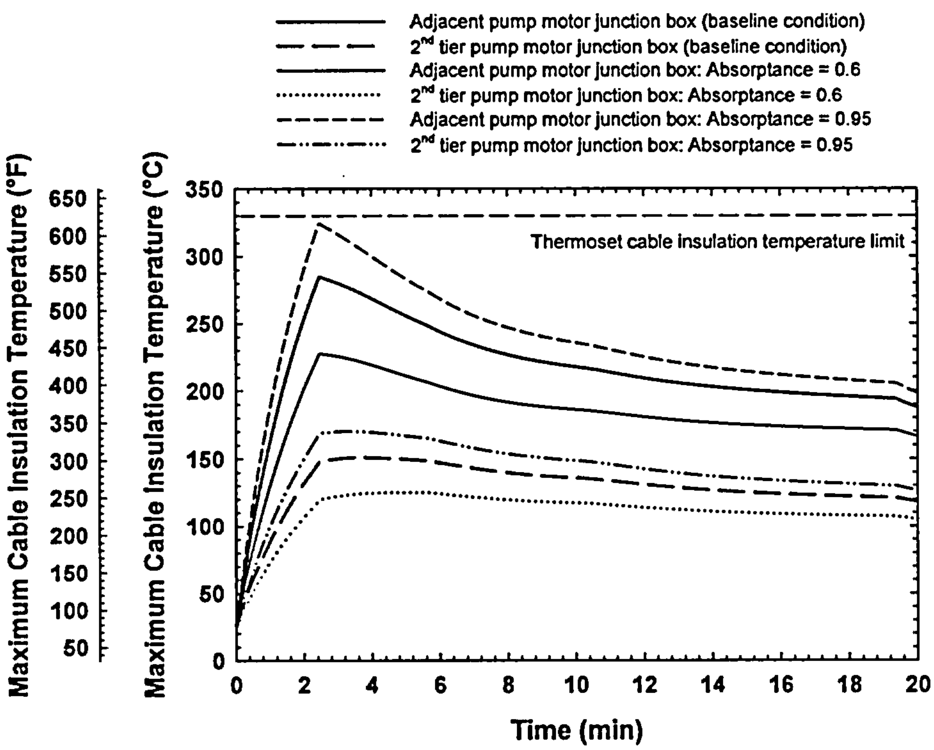


Figure A–27. Target Surface Temperature Profiles for Alternate Ventilation Scenarios where the Smoke Layer Remains above the Target

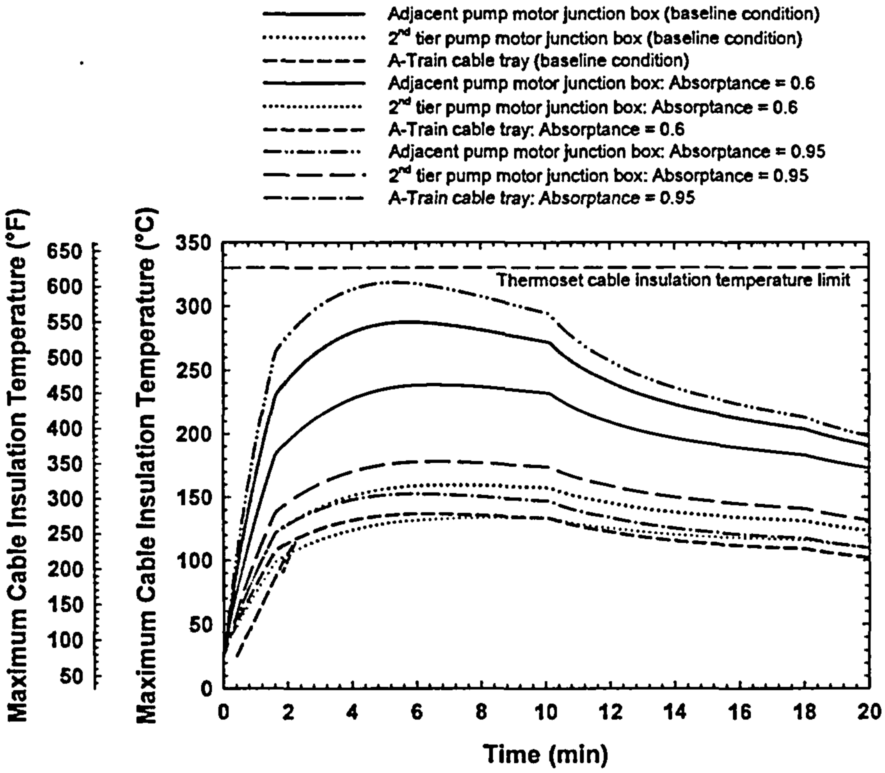
Figure A–27 indicates that adjacent pump motor box targets could be heated to the critical temperature for a C–Pump fire exposure if the smoke layer remains above the target. This is predicted to occur only if the exhaust fans operate continuously during the fire. It is important to note that these fans are not rated for removing combustion products and would likely fail when heated. Nevertheless, the sensitivity analysis indicates that adjacent pump motor box targets are susceptible to failure under certain conditions that cannot be precluded. As such, these targets are assumed to fail.

Target Response – Surface Absorbance

The most significant aspect of the target thermal response is the energy entering the system from the boundaries. The uncertainty associated with this is largely driven by the assumed absorption parameters at the surface with regard to thermal radiation. A value of 0.8 is assumed for the MEFS, which is a reasonable upper bound for steel surfaces and many painted surfaces [Incropera et al., 1985; Gebhart, 1971; Sparrow et al., 1978]. This parameter may range from less than 0.5 for polished metals to around 0.95 for some types of paints. Values of 0.6 and 0.95 are considered in this section. The results are shown in Figure A–28 for C–Pump fire scenarios and Figure A–29 for A–, B–, D–, or E–Pump fire scenarios.



Insert Figure A-28. Effect of Surface Absorbance on Response of Targets for C-Pump Fire Scenario



Insert Figure A–29. Effect of Surface Absorbance on Response of Targets for A–, B–, D–, or E–Pump Fire Scenarios

Figures A–28 and A–29 indicate that assumptions regarding the absorptance of the target surface do not change the conclusions, viz., a combined smoke layer-thermal radiation exposure would not cause an adjacent pump motor box, second tier pump motor box, or the A-Train cable tray targets to reach the critical temperature.

Conclusions

The following conclusions based on the MEFS calculations and the sensitivity analysis apply to the Unit 1 Service Water pump lubricant fire scenarios on the Pump Deck in the SWIS:

- A lubricant spill originating from a Unit 1 C–Pump is not predicted to damage the Unit 1 B–Pump and the D–Pump motor junction boxes; however, the sensitivity analysis indicates that conditions could arise where adjacent pump motor junction boxes fail. As such, a Unit 1 C–Pump is assumed to damage the Unit 1 B–Pump and the D–Pump motor junction boxes.
- A lubricant spill originating from a Unit 1 D–Pump or an E–Pump would likely result in damage to the Unit 1 C–, D–, and E–Pumps. This assumes the lubricant pools behind two pumps and damages an adjacent pump motor junction box target.

- A lubricant spill originating from a Unit 1 A–Pump or a B–Pump would likely result in damage to the Unit 1 A–, B–, and C–Pumps. This assumes the lubricant pools behind two pumps and damages an adjacent pump.
- A lubricant spill originating from any Unit 1 pump would not cause flashover and would not cause the smoke layer to exceed 330°C (625°F).
- A lubricant spill fire associated with any Unit 1 service water pump could cause the incident heat flux at a second tier pump target (i.e., pump adjacent to the adjacent pump) to exceed critical heat flux levels; however, the duration of the fire is not sufficient to cause the target surface temperature to exceed 330°C (625°F).
- A lubricant spill fire originating from a Unit 1 E–Pump could cause the incident heat flux at the Train A cable tray located near the east wall to exceed critical values; however, the duration of the fire is not sufficient for the flux to cause the target surface temperature to exceed 330°C (625°F).
- A sensitivity assessment of the ventilation conditions and target surface parameters indicates if the exhaust fans operate and remain functional, then the adjacent pumps would be impacted because they would not be immersed by the smoke layer. However, second tier pumps would not be impacted regardless of fan operation. Although the exhaust fans are not rated for combustion product temperatures, it is most conservative to assume that they could remain functional and prevent the smoke layer from immersing the targets. This does not affect the conclusions of the analysis.
- A sensitivity analysis indicates that the conclusions are not affected by the surface absorbance parameters.
- The results include a safety factor of at least two that is directly associated with the emissive power of the source fire.

A.3.2.4 Scenario 3

Scenario 3 is a lubricant pool fire that is located between the Unit 2 Service Water pumps and the south wall of the SWIS. Scenario 3A, the Unit 2 analog to Scenario 2A, involves lubricant that originates from the Unit 2 C-Pump and remains within the curb area behind the C-Pump. Scenario 3B, the Unit 2 analog to Scenario 2B, involves lubricant that originates from the Unit 2 A-, B-, D-, or E-Pumps and pools adjacent to the C-Pump curb area. The removal of PVC jacketed cable along the west wall precludes the need to consider fire propagation along the west wall raceway.

Targets

The targets that would be impacted by localized fire exposure are the adjacent pumps (motor junction boxes). Adjacent pumps are collectively a target when four or more pumps are impacted by the fire, as described in Section A.2.1.

The remaining targets in the SWIS would only be impacted by Scenarios 3A or 3B if the smoke layer temperature exceeds 500°C (932°F) (i.e., flashover) or if the smoke layer temperature exceeded 330°C (625°F) and the target were immersed in the smoke layer.

Summary

Scenarios 3A and 3B are bound in all respects by Scenarios 2A and 2B because:

- The volume of lubricant in the Unit 2 service water pumps is 30 L (8 gal), about 1/3 the volume associated with the Unit 1 service water pumps (85 L [22.5 gal]).
- The location is identical thus the fire sizes would be the same but the fire duration would be shorter.
- The junction motor box targets are targets are located in approximately the same position or higher, indicating that the smoke layer would immerse them sooner and block the flame radiation.
- There are no cable tray targets.

Given this, the results from Section A.3.2.2 apply to Scenario 3. Namely, the following conclusions may be conservatively drawn:

- A lubricant spill originating from a Unit 2 C–Pump is not predicted to damage the Unit 2 B–Pump and the D–Pump motor junction boxes; however, the sensitivity analysis indicates that conditions could arise where adjacent pump motor junction boxes fail. As such, a Unit 2 C–Pump is assumed to damage the Unit 2 B–Pump and the D–Pump motor junction boxes.
- A lubricant spill originating from a Unit 2 D–Pump or an E–Pump would likely result in damage to the Unit 2 C–, D–, and E–Pumps. This assumes the lubricant pools behind two pumps and damages an adjacent pump motor junction box target.
- A lubricant spill originating from a Unit 2 A–Pump or a B–Pump would likely result in damage to the Unit 2 A–, B–, and C–Pumps. This assumes the lubricant pools behind two pumps and damages an adjacent pump.
- A lubricant spill originating from any Unit 2 pump would not cause flashover and would not cause the smoke layer to exceed 330°C (625°F).
- A lubricant spill fire associated with any Unit 2 service water pump could cause the incident heat flux at a second tier pump target (i.e., pump adjacent to the adjacent pump) to exceed critical heat flux levels; however, the duration of the fire is not sufficient to cause the target surface temperature to exceed 330°C (625°F).
- A sensitivity assessment of the ventilation conditions and target surface parameters would indicate if the exhaust fans operate and remain functional, then the adjacent pumps would be impacted because they would not be immersed by the smoke layer. However, second tier pumps would not be impacted regardless of fan operation. Although the exhaust fans are not rated for combustion product temperatures, it is most conservative to assume that they could remain functional and prevent the smoke layer from immersing the targets. This does not affect the conclusions of the analysis.
- A sensitivity analysis would indicate that the conclusions are not affected by the surface absorptance parameters.
- The results include a safety factor of at least two that is directly associated with the emissive power of the source fire.

A.3.2.5 Summary

Table A–9 summarizes the fire scenario impact to the various targets in the SWIS. Values listed as "Not limiting" are significantly below the critical values or are bound by other parameters and were thus not determined.

Table A–9. MEFS Impact to Targets in the SWIS

MEFS	Target	Maximum Exposure Temperature (°C [°F])	Maximum Incident Heat Flux (kW/m² [Btu/s-ft²])	Maximum Surface Temperature (°C [°F])	Target Impacted by Scenario?
Scenario 1: Class A Fire in NE Corner	NE Corner Trays (Thermoset)	138 (280)	Not limiting	Not limiting	No target not damaged.
	NE Corner Trays (Thermoplastic)	114 (237)	Not limiting	Not limiting	Target not ignited.
	East wall tray	71 (160)	Not limiting	Not limiting	No
	Unit 1 pumps	71 (160)	Not limiting	Not limiting	No
	Unit 2 pumps	71 (160)	Not limiting	Not limiting	No
Scenario 2A: Unit 1 C–Pump Lubricant Fire	NE Corner Trays	178 (352)	Not limiting	Not limiting	No
	East wall tray	178 (352)	Not limiting	Not limiting	No
	Unit 1 adjacent pumps[1]	178 (352)	45.0 (4.0)	285 (545)	No, but safety margin is small
	Unit 1 2nd tier pumps[2]	178 (352)	19.1 (1.7)	151 (304)	No
	Unit 2 pumps	178 (352)	Not limiting	Not limiting	No
Scenario 2B: Unit 1 A–, B–, D–, or E–Pump Lubricant Fire	NE Corner Trays	248 (478)	Not limiting	Not limiting	No
	East wall tray	248 (478)	15.7 (1.4)	137 (279)	No
	Unit 1 adjacent pumps	248 (478)	44.5 (3.9)	287 (549)	No, but safety margin is small
	Unit 1 2nd tier pumps	248 (478)	18.9 (1.7)	160 (320)	No
	Unit 2 pumps	248 (478)	Not limiting	Not limiting	No
Scenario 3A: Unit 2 C–Pump Lubricant Fire[3]	NE Corner Trays	178 (352)	Not limiting	Not limiting	No
	West wall tray	178 (352)	15.7 (1.4)	Not limiting	Target not ignited.
	Unit 1 pumps	178 (352)	Not limiting	Not limiting	No
	Unit 2 adjacent pumps	178 (352)	45.0 (4.0)	285 (545)	No, but safety margin may be small
	Unit 2 2nd tier pumps	178 (352)	19.1 (1.7)	151 (304)	No
Scenario 3B: Unit 1 A–, B–, D–, or E–Pump Lubricant Fire[3]	NE Corner Trays	248 (478)	Not limiting	Not limiting	No
	West wall tray	248 (478)	15.7 (1.4)	137 (279)	No
	Unit 1 pumps	248 (478)	Not Limiting	Not limiting	No
	Unit 2 adjacent pumps	248 (478)	44.5 (3.9)	287 (549)	No, but safety margin may be small
	Unit 2 2nd tier pumps	248 (478)	18.9 (1.7)	160 (320)	No

[1]Adjacent pumps are those that are next to a pump behind which a lubricant pool fire burns.
[2]Second tier pumps are those next to adjacent pumps on the side opposite the fire.
[3]Based on Unit 1 pump fire scenarios bounding Unit 2 pump fire scenarios

A.4 Limiting Fire Scenarios (LFSs)

The Limiting Fire Scenarios (LFSs) associated with this analysis are presented in this section. The LFS is developed by altering one or more input parameters to determine the threshold at which a target would exceed the critical temperature or flux. Parameters that may be modified when determining the LFS include [NFPA 805, 2001]:

- The peak heat release rate of the source fire or the unit heat release rate;
- The duration of the source fire or the total mass of fuel available;
- The growth rate of the fire;
- The emissive power of the fire.

Increasing the peak heat release rate (or the unit heat release rate) alone may not always result in the smallest LFS margin. In some cases, an increased heat release rate and increased mass could result in target failure at a lower heat release rate. In some instances, such as where there is a confined liquid pool spill, the mass, surface area, and unit heat release rate are fixed. The LFS would in this case be incredible. Also, fire scenarios considered in this evaluation assume a rapid growth rate, thus this parameter is practical to include in the determination of the LFS.

Note that the safety margin, which is considered an estimate of the degree that the fire model input assumptions bound a particular fire scenario, is determined in Section A.7.3 and A.8.3 for CFAST and HEATING7, respectively. Some aspects of the safety margin were assessed when performing the sensitivity analysis for each scenario.

A.4.1 Scenario 1

Two LFSs are developed for Scenario 1, a Class A fire in the northeast corner of the SWIS. Because the exposure conditions to the Train B cable trays containing the thermoplastic cable insulation/jacket are less severe and had a greater margin of safety, only the Train A cable tray targets are considered. The first LFS is determined by increasing the peak heat release rate while maintaining a constant unit heat release rate of the fuel package until the exposure temperature at the Train A target cable trays is equal to the critical target surface temperature of 330°C (625°F). The second LFS is determined by increasing both the mass of the fuel package (via an increase in the duration at a given heat release rate) and the peak heat release rate while maintaining a constant unit heat release rate until the combined smoke layer-thermal plume exposure at the target cable trays equals the critical target surface temperature of 330°C (625°F).

Increasing the unit heat release rate, as may be the case if there were oily rags or Class B material mixed with the Class A material, was considered in the sensitivity analysis for this scenario. It was determined that there is a safety margin on the order of four associated with this type of scenario modification.

A.4.1.1 Peak Heat Release Rate Increase

The peak heat release rate of the MEFS Class A fuel package was increased until the exposure temperature at the surface of the target exceeded the critical exposure temperature of 330°C (625°F). The unit heat release rate is assumed constant such that the diameter of the source fire increases. The limiting heat release was determined using Equations A–9 through A–15 to be about 1,920 kW (1820 Btu/s). This is over five greater than the MEFS. No consideration was given for the time required to heat the target surface to 330°C (625°F) nor was the associated mass of material required to sustain the fire for the required time considered.

A.4.1.2 Mass and Heat Release Rate Increase

The mass and heat release rate of the Class A fuel package were increased to determine the LFS threshold. In this case, the unit heat release rate remains constant. The LFS in this case would be a thermal plume exposure to the northeast corner cable trays immersed in the hot smoke layer. The manner in which this is calculated is by first determining the temperature at the time the layer immerses the trays for a given heat release rate source fire using CFAST. Then, the calculated smoke layer temperature becomes the assumed ambient and Equations A–9 through A–15 are used to calculate the exposure temperature. When the plume temperature exceeds the critical temperature for the cable trays (330°C [625°F]), the LFS is found.

The results are shown in Figure A-30. The LFS for the northeast corner is approximately a 1,430 kW (1,360 Btu/s) source fire. The smoke layer requires 8.5 minutes to immerse the cable trays, thus the minimum mass of combustible material would be about 28.9 kg (64 lb) as calculated using Equation A–1. The LFS heat release rate determined in this manner is about four times the MEFS peak heat release heat release rate of 350 kW (332 Btu/s) and the required mass is about five times the assumed mass of 6.2 kg (13.6 lb) for the MEFS.

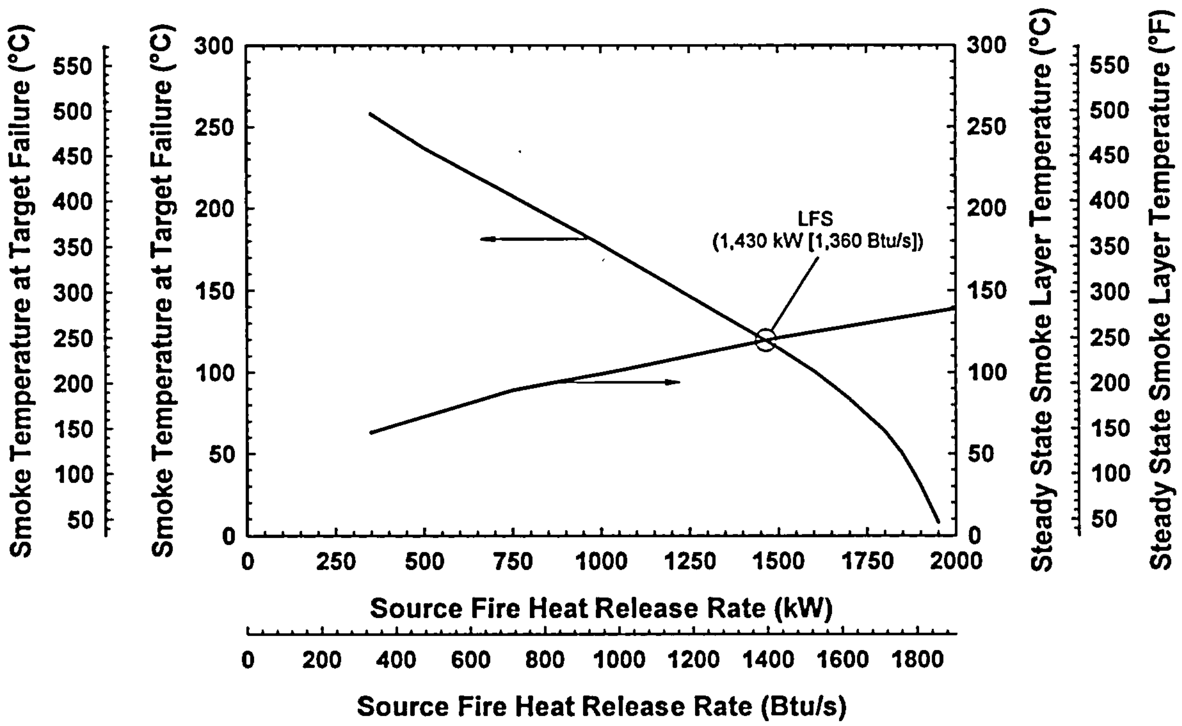


Figure A–30. Combined Smoke Layer–Thermal Plume LFS for the Northeast Corner of the SWIS

A.4.2 Scenario 2

Two LFSs are developed for Scenario 2, a Class B fire behind one or more of the Unit 1 service water pumps. The first is determined by increasing the emissive power of the flames until the target may be heated to the critical temperature of 330°C (625°F). The second is determined by increasing both the peak heat release rate of the source fire until the smoke layer exceeds the critical target surface temperature of 330°C (625°F).

Because temperatures reach a steady state condition in the SWIS, increasing the mass of fuel available and thus the duration if the heat release rate is fixed, would not impact the results and is not considered. The effects of an increase in fuel mass that leads to a larger fire are evaluated via an increase in the peak heat release rate and the flame emissive power.

A.4.2.1 Scenario 2A

Scenario 2A involves a lubricant spill originating from a Unit 1 C–, B–, D–, or E–Pump and pooling in the curbed area behind the C–Pump. The adjacent pumps are always the B– and D–Pumps and the second tier pumps are always the A– and E–Pumps.

The LFS for this scenario relative to a specific target is determined by increasing the emissive power of the flames until the target surface temperature is calculated to reach 330°C (625°F). A second LFS applicable to all targets is determined by increasing the peak heat release rate until the smoke layer temperature reaches 330°C (625°F). Consideration for ignition of thermoplastic cable targets is not necessary because the heat release rate is a variable parameter; ignition of the thermoplastic cable tray targets provides an increased heat release rate in the SWIS.

Figure A–31 shows the temperature response of the adjacent and second tier pump motor box targets for the baseline condition and the LFS emissive flame emissive power as calculated using the thermal model HEATING version 7.3. Section A.8 contains a HEATING template input file for determining the LFS for the Unit 1 C–Pump fire scenario. The results indicate that the LFS for an adjacent pump motor box target requires a flame with an emissive power about 20 percent greater than the MEFS flame emissive power, or 135 kW/m² (11.9 Btu/s-ft²). Likewise, the LFS for a second tier pump motor box target requires a flame with an emissive power 172 percent greater than the MEFS emissive power, or 306 kW/m² (27.0 Btu/s-ft²).

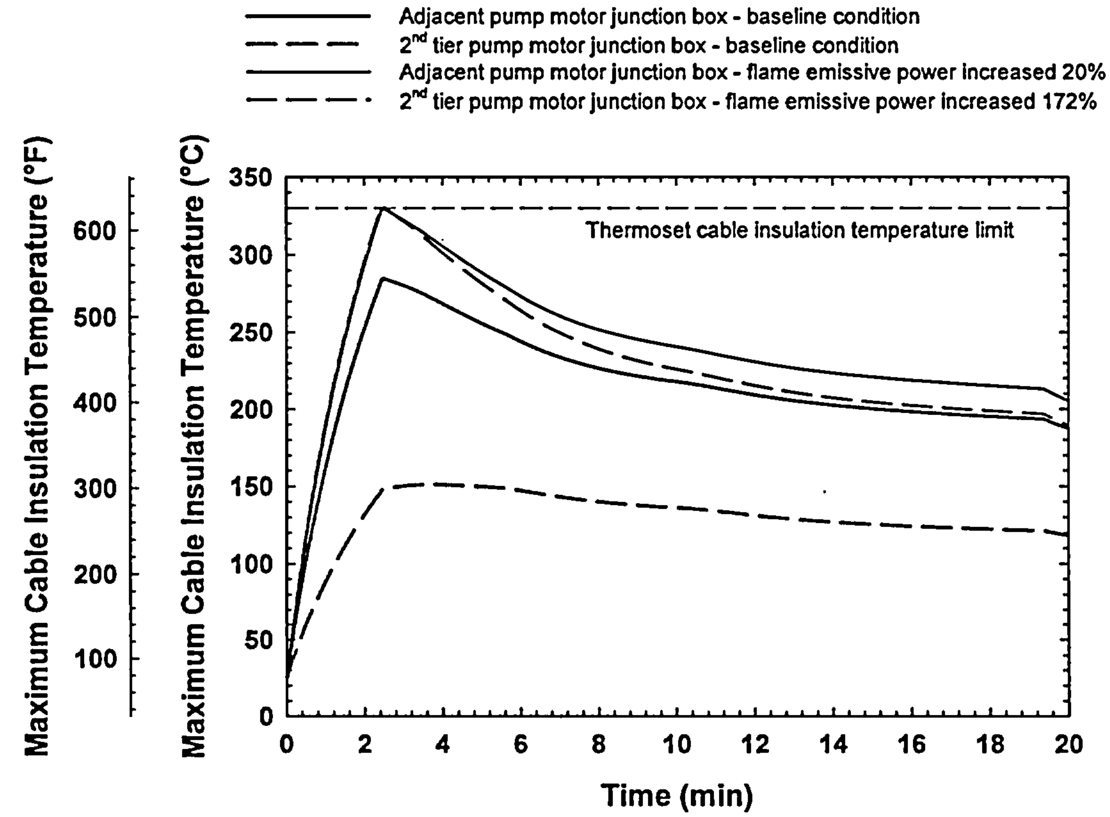


Figure A–31. Flame Emissive Power LFS for Unit 1 C–Pump Fire Exposing Various Targets

The LFS as determined by increasing the peak heat release rate of the lubricant fire was calculated using CFAST version 5.1.1. Section A.7 contains the CFAST input file used to determine the LFS. The resulting LFS heat release rate that causes a smoke layer temperature of 330°C (625°F) is 9,500 kW (9,000 Btu/s). This represents an increase of 250 percent above the Unit 1 C–Pump MEFS heat release rate.

A.4.2.2 Scenario 2B

Scenario 2B involves a lubricant spill originating from a Unit 1 A–, B–, D–, or E–Pump and pooling behind and directly damaging two pumps. The adjacent pump is always the C–Pump.

The LFS for this scenario relative to a specific target is determined by increasing the emissive power of the flames until the target surface temperature is calculated to reach 330°C (625°F). A second LFS applicable to all targets is determined by increasing the peak heat release rate until the smoke layer temperature reaches 330°C (625°F).

Figure A–32 shows the temperature response of the adjacent and second tier pump motor box targets for the baseline condition and the LFS emissive flame emissive power as calculated using the thermal model HEATING version 7.3. Section A.8 contains a HEATING template input file for determining the LFS for the Unit 1 A–, B–, D–, or E–Pump fire scenarios. The results indicate that the LFS for an adjacent pump motor box target requires a flame with an emissive power about 23 percent greater than the MEFS flame emissive power, or 137 kW/m² (11.1 Btu/s-ft²). Likewise, the LFS for a second tier pump motor box target requires a flame with an emissive power 192 percent greater than the MEFS emissive power, or 325 kW/m² (28.6 Btu/s-ft²) and the LFS for the A–Train cable tray target requires a flame emissive power 265% greater than the MEFS emissive power, or 406 kW/m² (35.8 Btu/s-ft²).

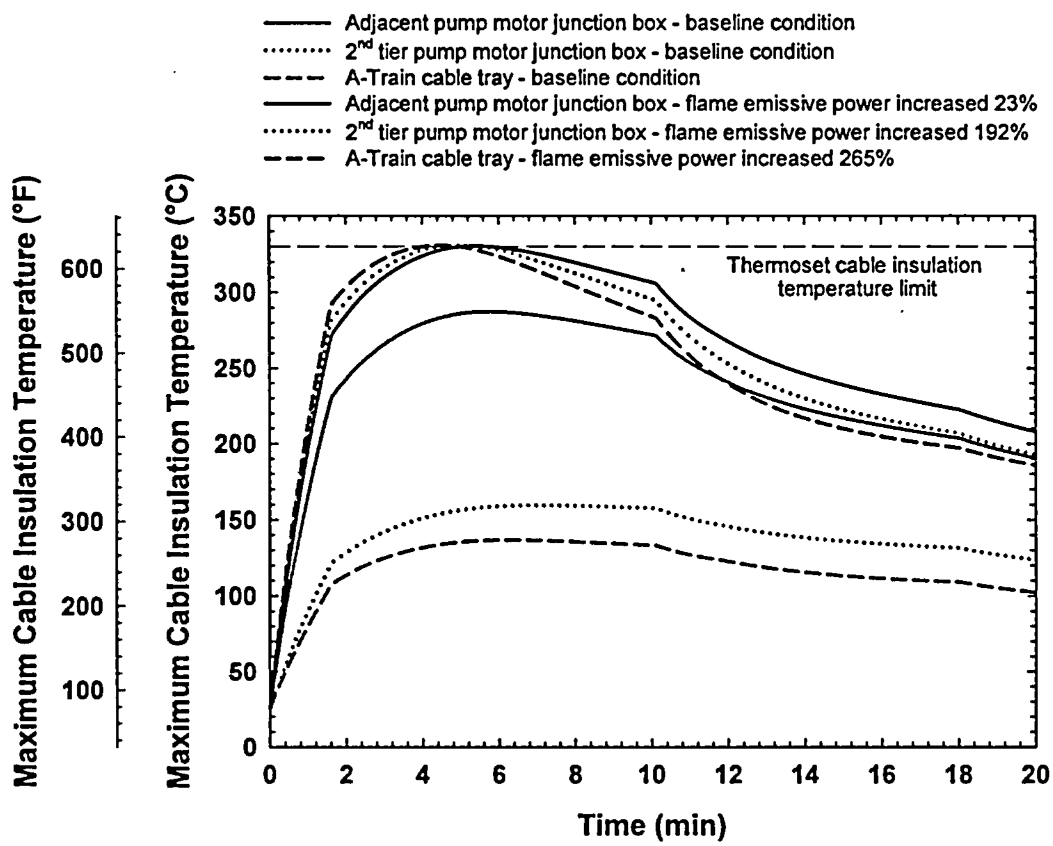


Figure A-32. Flame Emissive Power LFS for Unit 1 A–, B–, D–, or E–Pump Fire Exposing Various Targets

The LFS as determined by increasing the peak heat release rate of the lubricant fire was calculated using CFAST version 5.1.1. Section A.7 contains the CFAST input file used to determine the LFS. The resulting LFS heat release rate that causes a smoke layer temperature of 330°C (625°F) is 9,500 kW (9,000 Btu/s). This represents an increase 104 percent above the Unit 1 A–, B–, D–, or E–Pump MEFS heat release rates.

A.4.3 Scenario 3

Scenario 3 is bound in all respects by Scenario 2, including the LFS.

A.4.4 Summary

The following conclusions regarding the LFSs in the SWIS are based on the results above:

- The LFS for the northeast corner requires a peak heat release rate five times greater than the MEFS heat release rate without consideration of burning duration and fuel package mass. The LFS requires a peak heat release rate four times greater than the MEFS and a mass five times greater than that assumed for the MEFS fuel package if burning duration and layer formation are considered.

- The LFS peak heat release rate of a Unit 1 or Unit 2 service water pump lubricant fire is about 9,500 kW (9,000 Btu/s) or about 75 percent greater than the largest heat release rate postulated based on ground contour and drain locations.
- The LFS flame emissive power requires an increase of about 20 percent for adjacent pump motor junction box targets; 175 – 200% for second tier pump motor junction box target; and 265% for the A–Train cable tray target.
- The LFSs for the Unit 2 service water pumps are bound by the Unit 1 service water pump LFSs.

A.5 Fire Modeling Summary

The significant determinations in this analysis are as follows:

- Three MEFSs are postulated in Fire Zone 72A: a Class A combustible material fire near the northeast corner of the Strainer Pit; a Unit 1 pump lubricant fire, and a Unit 2 pump lubricant fire.
- A sensitivity analysis of ventilation and fuel parameters determined that the results and conclusions would not change with the exception of adjacent pump motor junction box targets. As a result, these targets are assumed to fail in the analysis.
- A Unit 1 pump lubricant fire can disable three Unit 1 Service Water pumps. If there is one that is out of service, then one pump will remain functional.
- A Unit 1 pump lubricant fire would not impact the A–Train cable tray near the east wall of the SWIS.
- A Unit 2 pump lubricant fire is bound by Unit 1 pump lubricant fires. Therefore, a single Unit 2 pump lubricant fire is assumed to disable up to three service water pumps.
- The LFS for the three scenarios varies depending on the target and parameter considered. For a fire in the northeast corner, the LFS heat release rate is between four and five times greater than the MEFS heat release rate. For pump lubricant fires, the LFS heat release rate is about 75 percent larger than the MEFS heat release rate. The LFS for flame emissive power is about 20 percent for adjacent pump motor junction box targets and over 175 – 265% for other targets. Note that adjacent pump motor box targets are assumed to fail based on the results of the sensitivity analysis.
- The sprinkler system in the SWIS is expected to operate within six minutes regardless of the local obstructions or ceiling contours for all scenarios considered except for the Class A material fire in the northeast corner. The Class A material fire in the northeast corner may not actuate the sprinkler system under certain circumstances.

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A.7 – CFAST Description and Input Files

A.7.1 CFAST Description

CFAST, a multi-zone computer fire simulation model, was used to calculate the peak smoke layer temperature in the atrium space [Peacock et al., 1993a; Jones et al., 2000]. CFAST was developed at the National Institute of Standards and Technology (NIST) for modeling steady and unsteady state burning rates in multiple compartment configurations. The initiating fire is user specified, but is adjusted by CFAST based on the available supply of oxygen. The model divides each compartment into two zones that change in vertical relationship as the fire develops. One zone is an upper hot smoke zone that contains the fire products and the other is a lower relatively smoke-free zone that is cooler than the upper zone. Within a zone the temperature, gas concentration, and smoke density are uniform.

The two-layer approach used by CFAST has evolved from observations of such layering in full-scale fire experiments [Jones et al., 2000]. While these experiments show some variation in conditions within the layers, these are small compared to the differences in conditions between the layers themselves. Thus, the zone model can produce a realistic simulation of the fire environment within a compartment under most conditions.

CFAST has the capability to calculate the upper and lower layer temperature, the smoke density, the vent flow rates, the component gas concentrations, the compartment boundary temperatures, the heat flux from the smoke layer to objects, the internal compartment pressure, and the interface elevation, all as a function of time. Multiple compartments and vents can be modeled as well as the mechanical ventilation.

The CFAST model and its predecessor FAST [Jones, 1995] have been extensively validated against well-instrumented full-scale tests. The results have been reported in peer-reviewed documents. References include the following: Jones et al. [1988, 2000], Nelson et al. [1991], Deal [1990], Duong [1990], Beard [1990, 1992], Peacock et al. [1993b, 1998], Dembsey et al. [1995], Collier [1995], Bailey et al. [1995], Chow [1992, 1996], Davis et al. [1996], Rockett [1997], Luo [1997], He et al. [1997, 1998], Luo et al. [1998], Reneke et al. [2001], and Tatem et al. [2004].

In addition to the peer-reviewed documents, the Nuclear Regulatory Commission (NRC) has also issued a report on computer fire models for use in Nuclear Power Plant Applications [Dey, 2002]. The report includes the CFAST model and concludes that the models reviewed can provide useful results for nuclear fire safety analysis.

CFAST input data includes the physical dimensions of the compartment, the compartment construction materials, the opening dimensions and elevations, the fire heat release rate, fuel composition, and the position of the fire in the specified room. Other parameters, not used in this analysis, include mechanical ventilation parameters, exterior wind conditions, secondary fire information, and various file, graphic, and convergence criteria.

A.7.2 CFAST Input Parameters

A.7.2.1 Physical Domain

The SWIS was modeled in CFAST as a 25.4 m (83 ft) by 17 m (55.6 ft) by 10.1 m (33 ft) high concrete space. The floor plan dimensions are modified slightly from the actual values to account for the south portion of the Pump Deck that extends beyond the area covered by the Strainer Pit. The volume is conserved and the aspect ratio of the length and width are maintained. The interior height of the SWIS is conservatively assumed to be at the base of the ceiling assembly, or 10.1 m (33 ft) above the Strainer Pit floor. Portions of the ceiling are above this elevation and would collect combustion products and reduce the smoke layer descent.

A single vent that is 2 m (6.5 ft) wide by 0.1 m (2 in) tall is placed at the floor of the Strainer Pit to relieve pressure. Actual leakage is expected to be greater because there are several door openings and there are removable ceiling panels that do not have smoke tight seals.

The Strainer Pit fires are located on the floor of the CFAST domain, or at 0 m (0 ft) elevation. The Pump Deck fires are located 6.6 m (21.6 ft) above the floor of the Strainer Pit, several inches above the base of the Pump Deck floor.

The Strainer Pit fire scenario is located in the corner. The pump lubricant fires are located against the wall. The location of the fire is important in CFAST to the extent that it is positioned near walls, corners, or in the open (unconfined) because the entrainment and the temperature of the smoke layer are adjusted accordingly. When a fire is located in the corner, the smoke layer temperature is maximized; however, the descent of the layer may be slower than if the fire were located against a wall or if it were unconfined [Jones et al., 2000].

The fires are simulated with the ceiling jet function, as recommended by Jones [2002].

A.7.2.2. Fuel Characteristics

The fuel characteristics that are required for simulating a fire in CFAST are:

- Heat of combustion;
- Radiant heat release rate fraction;
- Hydrogen to carbon ration;
- Soot yield; and
- Carbon monoxide to carbon dioxide yield fraction.

These characteristics generally vary from combustible fuel to fuel. In the SWIS evaluation, two distinct combustible fuel packages were used: a Class A mix of cellulose and plastic material (Scenario 1) and a hydrocarbon lubricant (Scenario 2).

Scenario 1

The combustion properties for the Class A fuel package are developed assuming the fuel package is one-half (by mass) cellulose material and one-half plastic material.

The properties are averaged from Tewarson [2002] and Babrauskas [2003], except for the radiant fraction. The radiant fraction is a credible lower bound estimate based on Tewarson [2002] and the result will be to maximize the smoke layer temperature predictions. The properties for Scenario 1 are as follows:

- Heat of combustion: 23,700 kJ/kg (10,200 Btu/lb)
- Radiant heat release rate fraction: 0.2
- Hydrogen to carbon ration: 0.111
- Soot yield: 0.024
- CO/CO_2 yield ratio: 0.013

Scenarios 2 and 3

The combustion properties for the pump lubricant fire are developed from the components of the Texaco Regal 68 oil. The lubricant is composed of a mixture of mineral oil (liquid paraffin) and naphthenic oils [Chevron, 2002; Fuel and Marine Marketing, 1999].

The properties were obtained from Tewarson [2002], Babrauskas [2003], and Fuel and Marine Marketing [1999], except for the radiant fraction. The radiant fraction is a credible lower bound estimate based on Tewarson [2002]. The properties for Scenarios 2 and 3 are as follows:

- Heat of combustion: 39,700 kJ/kg (17,100 Btu/lb)
- Radiant heat release rate fraction: 0.2
- Hydrogen to carbon ration: 0.0833
- Soot yield: 0.031
- CO/CO_2 yield ratio: 0.011

A.7.2.3. Fire Scenario Assumptions

The only assumptions that were used in the CFAST calculations were that there is a sixty second growth period for lubricant fires to reach the peak heat release rate, a one second growth period for the Class A combustible material fire in the northeast corner, and a one second decay period for all scenarios. The burning duration at the peak heat releaser remains the same; thus the assumed growth period is added to all time points that define the heat release rate curve. The purpose of incorporating a growth is to avoid predicting an artificially thin and hot smoke layer, which is a limitation of the two-zone approach. The decay period is the minimum possible when entering fire heat release rate data.

A.7.3 Safety Margin

The safety margin may be considered a confidence measure of the calculated results. The safety margin differs from the LFS in that it measures the relative conservatism of the MEFS relative to the assumed input parameters. It is not a measure of the safety factor; rather it is related to the model sensitivity to the input parameters. A safety margin greater than one indicates that the calculated results bound the input uncertainty for the particular parameters.

The safety margin is determined by estimating the degree that various input parameter assumptions are bounding. Only input parameters that could have a significant impact on the calculation results are used to determine the safety margin. These include the following for the CFAST evaluations:

- The lower oxygen limit for combustion;
- The fraction of energy released as radiation; and
- The fire location.

Because a detailed sensitivity analysis was not performed, the parameters that impact the safety margin and the safety margin itself are estimates.

The lower oxygen limit in this analysis is ten percent. Data available indicate that the lower oxygen limit under fire conditions varies from zero to fifteen percent, depending on the smoke layer composition and temperature [Peatross et al., 1997; Beyler, 1984, 2002b; NIST, 2004; Back et al, 2000]. A value of zero percent is assumed when determining the safety margin. Similarly, the radiant fraction assumed in the analysis was 0.2 whereas data support values up to 0.4 [Tewarson, 2002].

The fire location assumed in the model was a corner for Scenario 1 and against a flat wall for Scenarios 2 and 3. CFAST reduces the thermal plume entrainment for corner and wall fires and the result is an increase in the smoke layer temperature and an increase in the rate of smoke layer descent. This is a bounding assumption because fuel packages may be positions somewhat away from the wall or corner.

The impact of the assumptions regarding these parameters relative to likely values on the peak smoke layer temperature is summarized in Table A–10 for Scenario 1 and Scenario 2A, the most severe pump fire scenario. The safety margin is computed using the temperature increase, assuming an ambient temperature of 25 °C (77 °F). Section A.7.4 contains the LFS template input file for Scenarios 1 and 2A.

Table A-10. Safety Margin for CFAST Fire Scenarios

Scenario	Modified Parameter	Peak Smoke Layer Temperature (°C [°F])		Safety Margin
		Base Case	Modification	
Scenario 1: Class A fire in NE Corner	Oxygen Limit (0%)	71 (160)	71 (160)	1.0
	Oxygen Limit (15%)		71 (160)	1.0
	Radiant Fraction		60 (140)	1.2
	Fire Location		42 (108)	2.7
Scenario 2A Unit	Oxygen Limit (0%)	248 (478)	254 (489)	0.97
	Oxygen Limit (15%)		248 (478)	1.0
	Radiant Fraction		233 (451)	1.07
	Fire Location		248 (478)	1.0

The safety margin for Scenario 1 is thus between 1 and 2.7, depending on the particular parameter. Likewise, the safety margin for Scenario 2A (and Scenarios 2B, 3A, and 3B) is between 0.97 and 1.07, depending on the particular parameter. The only parameter that results in a lower safety margin is when the LOI is reduced from ten percent. However, for temperatures in the range of 250°C (482°F) the LOI is greater than 12 percent; thus the overall safety margin is still greater than unity.

The impact of mechanical and natural ventilation was examined as part of the sensitivity analysis. It was found that the ventilation assumptions have little effect on the compartment temperature, actually reducing is by a few degrees due to energy leaving the domain. Mechanical ventilation was shown to cause the smoke layer to remain above some targets thus changing the nature of the problem. If this were to occur, the adjacent pump motor box targets could be damaged by radiant heating directly from the flame. This finding was incorporated directly into the conclusions of the analysis.

A.7.4 CFAST Input Files

A.7.4.1 MEFS CFAST Input File for Scenario 1

```
VERSN    5 SWIS: MEFS 1 - Class A in NE Corner
ADUMP   MEFS-01.csv  NWS
DUMPR   MEFS-01.hi
TIMES    1200  5  5  5  0
TAMB    298.0 101300.0  0.
EAMB    298.0  101300.0  0.
HI/F    0.0
WIDTH   25.43
DEPTH   16.95
HEIGHT  10.06
HVENT   1  2  1   2.0   0.1   0.0
CEILI   CONCRETE
WALLS   CONCRETE
FLOOR   CONCRETE
CHEMI   16.  40.  10.  23700000   300.  400.  0.2
LFBO   1
LFBT   2
FPOS   16.95 25.43 0.0
FTIME  1. 200. 400. 600. 601. 1200.
FHIGH  0.0 0.0 0.0 0.0 0.0 0.0 0.0
FAREA  0.3 0.3 0.3 0.3 0.3 0.3 0.3
FQDOT  0.0 350e3 350e3 100e3 100e3 0.0 0.0
```

```
CJET   CEILING
HCR    0.111 0.111 0.111 0.111 0.111 0.111 0.111
OD     0.024 0.024 0.024 0.024 0.024 0.024 0.024
CO     0.013 0.013 0.013 0.013 0.013 0.013 0.013
STPMAX 1.0
```

A.7.4.2 MEFS CFAST Input File for Scenario 2A

```
VERSN    5  SWIS: MEFS 2A - 90 qts Lubricant behind Unit 1 C-Pump
ADUMP   MEFS-02A.csv  NWS
DUMPR   MEFS-02A.hi
TIMES    1200  5  5  5  0
TAMB    298.0  101300.0  0.
EAMB    298.0  101300.0  0.
HI/F    0.0
WIDTH   25.43
DEPTH   16.95
HEIGHT  10.06
HVENT   1  2  1   2.0   0.1   0.0
CEILI   CONCRETE
WALLS   CONCRETE
FLOOR   CONCRETE
CHEMI   16.  40.  10.  39700000   300.  400.  0.2
LFBO   1
LFBT   2
FPOS   5.0 5.0 0.0
FTIME  60. 1156. 1157. 1200.
FHIGH  6.63 6.63 6.63 6.63 6.63
FAREA  1.95 1.95 1.95 1.95 1.95
FQDOT  0.0 2710e3 2710e3 0e3 0e3
CJET   CEILING
HCR    0.0833 0.0833 0.0833 0.0833 0.0833
OD     0.031 0.031 0.031 0.031 0.031
CO     0.012 0.012 0.012 0.012 0.012
HCL    0.031 0.031 0.031 0.031 0.031
STPMAX   1.0
```

A.7.4.3 MEFS CFAST Input File for Scenario 2B

```
VERSN    5  SWIS: MEFS 2B - 90 qts Lubr behind A&B or D&E Unit 1 Pumps
ADUMP   MEFS-02B.csv  NWS
DUMPR   MEFS-02B.hi
TIMES    1200  5  5  5  0
TAMB    298.0  101300.0  0.
EAMB    298.0  101300.0  0.
HI/F    0.0
WIDTH   25.43
DEPTH   16.95
HEIGHT  10.06
HVENT   1  2  1   2.0   0.1   0.0
CEILI   CONCRETE
WALLS   CONCRETE
FLOOR   CONCRETE
CHEMI   16.  40.  10.  39700000   300.  400.  0.2
LFBO   1
LFBT   2
FPOS   5.0 5.0 0.0
FTIME  60. 608. 609. 1200.
FHIGH  6.63 6.63 6.63 6.63 6.63
FAREA  3.9 3.9 3.9 3.9 3.9
FQDOT  0.0 5220e3 5220e3 0e3 0e3
CJET   CEILING
HCR    0.0833 0.0833 0.0833 0.0833 0.0833
OD     0.031 0.031 0.031 0.031 0.031
CO     0.012 0.012 0.012 0.012 0.012
STPMAX 1.0
```

A.7.4.4 Sensitivity Analysis CFAST Input File for Scenario 1 – Ventilation Conditions

```
VERSN    5  SWIS: Sensitivity template (ventilation)- Class A in NE Corner
ADUMP   SEN-1A1.csv  NWS
DUMPR   SEN-1A1.hi
TIMES   1200  5  5  5  0
TAMB    298.0 101300.0  0.
EAMB    298.0  101300.0  0.
HI/F    0.0
WIDTH   25.43
DEPTH   16.95
HEIGHT  10.06
HVENT   1  2  1   2.0    0.1    0.0
#Door to 72D - treat as ambient
HVENT   1  2  2    0.91  8.8   6.63
#Door to 72E - treat as ambient
#HVENT   1  2  3    0.91  8.8    6.63
#INELV   1  10.06  2  10.06  3  10.06  4  10.06
#INELV   5  10.06  6  10.06  7  10.06  8  10.06
#MVOPN   1  1 H 10.06  1.0
#MVOPN   2  4 H 10.06  1.0
#MVOPN   1  5 H 10.06  1.0
#MVOPN   2  8 H 10.06  1.0
#MVDCT   1  2  0.5  1.0  0.0002 0.0 1.0 0.0 1.0
#MVDCT   3  4  0.5  1.0  0.0002 0.0 1.0 0.0 1.0
#MVDCT   5  6  0.5  1.0  0.0002 0.0 1.0 0.0 1.0
#MVDCT   7  8  0.5  1.0  0.0002 0.0 1.0 0.0 1.0
#MVFAN   2  3  0.0 1907.0 14.15
#MVFAN   6  7  0.0 1907.0 14.15
CEILI   CONCRETE
WALLS   CONCRETE
FLOOR   CONCRETE
CHEMI   16.  40.  10.  23700000   300.  400.  0.2
LFBO   1
LFBT   2
FPOS   16.95 25.43 0.0
FTIME  1. 200. 400. 600. 601. 1200.
FHIGH  0.0 0.0 0.0 0.0 0.0 0.0 0.0
FAREA  0.3 0.3 0.3 0.3 0.3 0.3 0.3
FQDOT  0.0 350e3 350e3 100e3 100e3 0.0 0.0
CJET   CEILING
HCR    0.111 0.111 0.111 0.111 0.111 0.111 0.111
OD     0.024 0.024 0.024 0.024 0.024 0.024 0.024
CO     0.013 0.013 0.013 0.013 0.013 0.013 0.013
STPMAX 0.1
```

A.7.4.5 Sensitivity Analysis CFAST Input File for Scenario 1 – Ventilation Conditions

```
VERSN    5  SWIS: Sensitivity template (fuel) - Class A in NE Corner 350 kW
ADUMP   Sen-1B1.csv  NWS
DUMPR   Sen-1B1.hi
TIMES    1000  5  5  5  0
TAMB    298.0 101300.0  0.
EAMB    298.0  101300.0  0.
HI/F    0.0
WIDTH   25.43
DEPTH   16.95
HEIGHT  10.06
HVENT   1  2  1   2.0    0.1    0.0
CEILI   CONCRETE
WALLS   CONCRETE
FLOOR   CONCRETE
CHEMI   16.  40.  10.  23700000   300.  400.  0.2
LFBO   1
LFBT   2
```

```
FPOS   16.95 25.43 0.0
FTIME  1. 1000.
FHIGH  0.0 0.0 0.0
FAREA  0.3 0.3 0.3
#increase heat release rate
FQDOT  0.0 350e3 350e3
CJET   CEILING
HCR    0.111 0.111 0.111
OD     0.024 0.024 0.024
CO     0.013 0.013 0.013
STPMAX 1.0
```

A.7.4.6 LFS CFAST Input File Template for Scenario 1

```
VERSN    5  SWIS: LFS 1 - Class A in NE Corner 1430 kW
ADUMP   LFS-1-1.csv  NWS
DUMPR   LFS-1-1.hi
TIMES    1200  5  5  5  0
TAMB    298.0 101300.0  0.
EAMB    298.0  101300.0  0.
HI/F    0.0
WIDTH   25.43
DEPTH   16.95
HEIGHT  10.06
HVENT   1  2  1   2.0   0.1   0.0
CEILI   CONCRETE
WALLS   CONCRETE
FLOOR   CONCRETE
CHEMI   16.  40.  10.  23700000   300.  400.  0.2
LFBO   1
LFBT   2
FPOS   16.95 25.43 0.0
FTIME  1. 2000.
FHIGH  0.0 0.0 0.0
FAREA  0.3 0.3 0.3
FQDOT  0.0 1430e3 1430e3
CJET   CEILING
HCR    0.111 0.111 0.111
OD     0.024 0.024 0.024
CO     0.013 0.013 0.013
STPMAX 1.0
```

A.7.4.7 Safety Margin CFAST Input File Template for Scenario 1

```
VERSN    5  SWIS: Safety Margin Template Scen. 1
ADUMP   SM-1-1.csv  NWS
DUMPR   SM-1-1.hi
TIMES    1200  5  5  5  0
TAMB    298.0 101300.0  0.
EAMB    298.0  101300.0  0.
HI/F    0.0
WIDTH   25.43
DEPTH   16.95
HEIGHT  10.06
HVENT   1  2  1   2.0   0.1   0.0
CEILI   CONCRETE
WALLS   CONCRETE
FLOOR   CONCRETE
CHEMI   16.  40.  10.  23700000   300.  400.  0.2
LFBO   1
LFBT   2
FPOS   16.95 25.43 0.0
FTIME  1. 2000.
FHIGH  0.0 0.0 0.0
FAREA  0.3 0.3 0.3
FQDOT  0.0 1430e3 1430e3
CJET   CEILING
```

```
HCR    0.111 0.111 0.111
OD     0.024 0.024 0.024
CO     0.013 0.013 0.013
STPMAX 1.0
```

A.7.4.8 Sensitivity Analysis CFAST Input File Template for Scenario 2A – Ventilation Conditions

```
VERSN    5 SWIS:  Sensitivity template (ventilation) Scenario 2A
ADUMP   SEN-2A1.csv  NWS
DUMPR   SEN-2A1.hi
TIMES    1200  5  5  5  0
TAMB    298.0  101300.0  0.
EAMB    298.0  101300.0  0.
HI/F    0.0
WIDTH   25.43
DEPTH   16.95
HEIGHT  10.06
HVENT   1  2  1   2.0   0.1   0.0
#Door to 72D - treat as ambient
#HVENT  1  2  2  0.91 8.8 6.63
#Door to 72E - treat as ambient
#HVENT  1  2  3  0.91 8.8 6.63
#INELV   1  10.06  2  10.06  3 10.06  4  10.06
#INELV   5  10.06  6  10.06  7 10.06  8  10.06
#MVOPN   1   1   H 10.06   1.0
#MVOPN   2   4   H 10.06   1.0
#MVOPN   1   5   H 10.06   1.0
#MVOPN   2   8   H 10.06   1.0
#MVDCT   1   2  0.5  1.0  0.0002 0.0 1.0 0.0 1.0
#MVDCT   3   4  0.5  1.0  0.0002 0.0 1.0 0.0 1.0
#MVDCT   5   6  0.5  1.0  0.0002 0.0 1.0 0.0 1.0
#MVDCT   7   8  0.5  1.0  0.0002 0.0 1.0 0.0 1.0
#MVFAN   2   3  0.0 1907.0 14.15
#MVFAN   6   7  0.0 1907.0 14.15
CEILI   CONCRETE
WALLS   CONCRETE
FLOOR   CONCRETE
CHEMI   16.  40.  10.  39700000   300.  400.  0.2
LFBO   1
LFBT   2
FPOS   5.0 5.0 0.0
FTIME  60. 1156. 1157. 1200.
FHIGH  6.63 6.63 6.63 6.63 6.63
FAREA  1.95 1.95 1.95 1.95 1.95
FQDOT  0.0 2710e3 2710e3 0e3 0e3
CJET   CEILING
HCR    0.0833 0.0833 0.0833 0.0833 0.0833
OD     0.031 0.031 0.031 0.031 0.031
CO     0.012 0.012 0.012 0.012 0.012
HCL    0.031 0.031 0.031 0.031 0.031
STPMAX 1.0
```

A.7.4.9 Sensitivity Analysis CFAST Input File Template for Scenario 2B – Ventilation Conditions

```
VERSN    5 SWIS:  Sensitivity template (ventilation) Scenario 2B
ADUMP   SEN-2B1.csv  NWS
DUMPR   SEN-2B1.hi
TIMES    1200  5  5  5  0
TAMB    298.0  101300.0  0.
EAMB    298.0  101300.0  0.
HI/F    0.0
WIDTH   25.43
DEPTH   16.95
HEIGHT  10.06
```

```
HVENT   1  2  1   2.0   0.1   0.0
#Door to 72D - treat as ambient
#HVENT  1  2  2  0.91 8.8 6.63
#Door to 72E - treat as ambient
#HVENT  1  2  3  0.91 8.8 6.63
#INELV   1  10.06  2  10.06  3 10.06  4  10.06
#INELV   5  10.06  6  10.06  7 10.06  8  10.06
#MVOPN   1   1   H 10.06   1.0
#MVOPN   2   4   H 10.06   1.0
#MVOPN   1   5   H 10.06   1.0
#MVOPN   2   8   H 10.06   1.0
#MVDCT   1   2  0.5  1.0  0.0002 0.0 1.0 0.0 1.0
#MVDCT   3   4  0.5  1.0  0.0002 0.0 1.0 0.0 1.0
#MVDCT   5   6  0.5  1.0  0.0002 0.0 1.0 0.0 1.0
#MVDCT   7   8  0.5  1.0  0.0002 0.0 1.0 0.0 1.0
#MVFAN   2   3  0.0 1907.0 14.15
#MVFAN   6   7  0.0 1907.0 14.15
CEILI   CONCRETE
WALLS   CONCRETE
FLOOR   CONCRETE
CHEMI   16.  40.  10.  39700000   300.  400.  0.2
LFBO   1
LFBT   2
FPOS   5.0 5.0 0.0
FTIME  60. 608. 609. 1200.
FHIGH  6.63 6.63 6.63 6.63 6.63
FAREA  3.9 3.9 3.9 3.9 3.9
FQDOT  0.0 5220e3 5220e3 0e3 0e3
CJET   CEILING
HCR    0.0833 0.0833 0.0833 0.0833 0.0833
OD     0.031 0.031 0.031 0.031 0.031
CO     0.012 0.012 0.012 0.012 0.012
STPMAX 1.0
```

A.7.4.10 LFS CFAST Input File Template for Scenarios 2A and 2B

```
VERSN    5  SWIS: LFS 2AB
ADUMP   LFS-2AB.csv  NWS
DUMPR   LFS-2AB.hi
TIMES    1200  5  5  5  0
TAMB    298.0  101300.0  0.
EAMB    298.0  101300.0  0.
HI/F    0.0
WIDTH   25.43
DEPTH   16.95
HEIGHT  10.06
HVENT   1  2  1   2.0   0.1   0.0
CEILI   CONCRETE
WALLS   CONCRETE
FLOOR   CONCRETE
CHEMI   16.  40.  10.  39700000   300.  400.  0.2
LFBO   1
LFBT   2
FPOS   5.0 5.0 0.0
FTIME  60. 1200.
FHIGH  6.63 6.63 6.63
FAREA  1.95 1.95 1.95
FQDOT  0.0 9500e3 9500e3
CJET   CEILING
HCR    0.0833 0.0833 0.0833
OD     0.031 0.031 0.031
CO     0.012 0.012 0.012
HCL    0.031 0.031 0.031
STPMAX 1.0
```

A.7.4.11 Safety Margin CFAST Input File for Scenario 2B

```
VERSN   5  SWIS: Safety Margin Template Scenario 2B template
ADUMP   SM-2B1.csv  NWS
DUMPR   SM-2B1.hi
TIMES    1200  5  5  5  0
TAMB    298.0  101300.0  0.
EAMB    298.0  101300.0  0.
HI/F    0.0
WIDTH   25.43
DEPTH   16.95
HEIGHT  10.06
HVENT   1  2  1   2.0   0.1   0.0
CEILI   CONCRETE
WALLS   CONCRETE
FLOOR   CONCRETE
CHEMI   16.  40.  10.  39700000   300.  400.  0.2
#Radiant fraction - 0.4
#CHEMI   16.  40.  10.  39700000   300.  400.  0.4
#LOI - 0.0
#CHEMI   16.  40.  0.  39700000   300.  400.  0.4
#LOI - 15.0
#CHEMI   16.  40.  0.  39700000   300.  400.  0.4
LFBO   1
LFBT   2
FPOS   5.0 5.0 0.0
#Fire Location
#FPOS   0.0 5.0 0.0
FTIME  60. 608. 609. 1200.
FHIGH  6.63 6.63 6.63 6.63 6.63
FAREA  3.9 3.9 3.9 3.9 3.9
FQDOT  0.0 5220e3 5220e3 0e3 0e3
CJET   CEILING
HCR    0.0833 0.0833 0.0833 0.0833 0.0833
OD     0.031 0.031 0.031 0.031 0.031
CO     0.012 0.012 0.012 0.012 0.012
STPMAX 1.0
```

A.8 – HEATING7 Description and Input Files

A.8.1 HEATING7 Description

HEATING7 (version 7.3) is a multi-dimensional finite difference general purpose heat transfer model [Childs, 1998]. The model can solve steady-state and/or transient heat conduction problems in one-, two-, or three-dimensional Cartesian, cylindrical, or spherical coordinates. A model may include multiple materials, and the thermal conductivity, density, and specific heat of each material may be both time- and temperature-dependent. The thermal conductivity may also be anisotropic. Materials may also undergo a change of phase. Thermal properties of materials may be input or may be extracted from a material properties library. Heat- generation rates may be dependent on time, temperature, and position, and boundary temperatures may be time- and position-dependent. The boundary conditions, which may be surface-to-environment or surface-to-surface, may be specified temperatures or any combination of prescribed heat flux, forced convection, natural convection, and radiation. The boundary condition parameters may be time- and/or temperature-dependent. General graybody radiation problems may be modeled with user-defined factors for radiant exchange. The mesh spacing may be variable along each axis. HEATING7 uses a run-time memory allocation scheme to avoid having to recompile to match memory requirements for each specific problem. HEATING (version 7.3) utilizes free-form input.

A.8.2 HEATING7 Input Parameters

The input parameters that are necessary for the HEATING7 evaluation are grouped into material properties and boundary conditions.

A.8.2.1 Material Properties

Thermal Conductivity

The thermal conductivity for steel as a function of temperature is shown in Table A–11. Because the critical temperature of the target is less than 400°C (750°F), the thermal conductivity of the copper and PVC jacket material are essentially temperature independent in this analysis.

Copper [Holman, 1990]: 386 W/m-°C (223 Btu/s-ft-°F)
PVC [Marks, 1996]: 0.17 W/m-°C (0.098 Btu/s-ft-°F)

Table A–11. Temperature Dependent Thermal Conductivity of Steel [Abrams, 1978]

Temp (°C [°F])	k (W/m-°C [Btu/s-ft-°F])	Temp (°C [°F])	k (W/m-°C [Btu/s-ft-°F])	Temp (°C [°F])	k (W/m-°C [Btu/s-ft-°F])	Temp (°C [°F])	k (W/m-°C [Btu/s-ft-°F])
20 (68)	46.0 (26.6)	316 (600)	42.8 (24.7)	649 (1,200)	32.8 (19.0)	816 (1,500)	29.0 (16.7)
38 (100)	46.0 (26.6)	371 (700)	41.0 (24.0)	677 (1,250)	32.1 (18.6)	843 (1,550)	27.2 (15.7)
73 (163)	46.4 (26.8)	427 (800)	39.5 (22.8)	704 (1,300)	31.4 (18.1)	871 (1,600)	26.4 (15.3)
149 (300)	45.7 (26.4)	482 (900)	37.8 (21.8)	732 (1,350)	30.9 (17.9)	899 (1,650)	26.7 (15.4)
204 (400)	44.8 (25.9)	538 (1,000)	36.4 (21.0)	760 (1,400)	30.5 (17.6)	927 (1,700)	26.8 (15.5)
260 (500)	43.8 (25.3)	593 (1,100)	34.7 (20.1)	788 (1,450)	30.0 (17.3)	1,038 (1,900)	27.7 (16.0)

Thermal Heat Capacity

The thermal heat capacity for steel as a function of temperature is shown in Table A–12. The thermal heat capacity for PVC as a function of temperature over the range of interest is shown in Table A–13. The heat capacity for copper is essentially constant of the temperature range expected in the cable core.

Copper [Holman, 1990]: 383 J/kg-°C (0.0917 Btu/lb-°F)

Table A–12. Temperature Dependant Heat Capacity of Steel [Abrams, 1978]

Temp (°C [°F])	c_p (J/kg-°C [Btu/lb-°F])	Temp (°C [°F])	c_p (J/kg-°C [Btu/lb-°F])	Temp (°C [°F])	c_p (J/kg-°C [Btu/lb-°F])	Temp (°C [°F])	c_p (J/kg-°C [Btu/lb-°F])
20 (68)	467 (0.112)	316 (600)	558 (0.134)	649 (1,200)	777 (0.186)	816 (1,500)	568 (0.136)
38 (100)	471 (0.113)	371 (700)	580 (0.139)	677 (1,250)	810 (0.194)	843 (1,550)	535 (0.128)
73 (163)	484 (0.116)	427 (800)	606 (0.145)	704 (1,300)	1,098 (0.26)	871 (1,600)	522 (0.125)
149 (300)	501 (0.12)	482 (900)	641 (0.153)	732 (1,350)	1,410 (0.34)	899 (1,650)	533 (0.127)
204 (400)	518 (0.124)	538 (1,000)	690 (0.165)	760 (1,400)	1,012 (0.24)	927 (1,700)	568 (0.136)
260 (500)	536 (0.128)	593 (1,100)	736 (0.176)	788 (1,450)	727 (0.17)	1,038 (1,900)	584 (0.14)

Table A–13. Temperature Dependant Heat Capacity of PVC [Marks, 1996]

Temp (°C [°F])	c_p (J/kg-°C [Btu/lb-°F])	Temp (°C [°F])	c_p (J/kg-°C [Btu/lb-°F])	Temp (°C [°F])	c_p (J/kg-°C [Btu/lb-°F])
27 (81)	950 (0.227)	87 (189)	1,457 (0.349)	107 (225)	1,569 (0.376)

Density

The density for the steel, PVC, and copper is constant of the temperature range considered.

Steel [Abrams, 1978]: 7,800 kg/m³ (486 lb/ft³)
Copper [Holman, 1990]: 8,954 kg/m³ (558 lb/ft³)
PVC [Johnson, 1994]: 1,500 kg/m³ (93.5 lb/ft³)

A.8.2.2 Boundary Conditions

Boundary conditions are applied in the following form [Childs, 1998]:

$$\dot{q}''_N = \alpha_t \dot{q}''_I + A\left(T_a^4 - T_s^4\right) + h\left(T_a - T_s\right)^n \qquad \text{(A–25)}$$

where $\dot{q}''_N$ is the net boundary heat flux (kW/m² [Btu/s-ft²]), α_t is the absorbance of the target surface (0.8), $\dot{q}''_I$ is the incident heat flux from the source fire (kW/m² [Btu/s-ft²]), A is a radiation parameter that includes the Stefan-Bolzmann constant, the radiation configuration factor, and the surface absorbance (kW/m²-K⁴ [Btu/s-ft²-°R⁴]), h is the convection coefficient (kW/m²-Kⁿ [Btu/s-ft²-°Rⁿ]), and n is the natural convection coefficient. The ambient temperature is assumed to be 20°C (68°F). As previously noted, ignoring the smoke layer is bounding for targets located at least 2.3 m (7.5 ft) from the source fire for scenarios in the SWIS. This is because the smoke layer absorbs the flux from the fire thus reducing the overall exposure.

The incident heat flux is determined for each scenario evaluated and is a function of the target location, the source fire emissive power, and other factors described in the main report. The radiation parameter that is used in this evaluation is 4.53×10^{-11} kW/m²-K^4 [3.8×10^{-13} Btu/s-ft²-°R^4], which assumes the configuration factor is unity and that the surface absorbance is 0.8, consistent with various types of metals and coatings [Holman, 1990; Incropera et al., 1985]. The convection coefficient is assumed to be 0.00131 kW/m²-K$^{1.33}$ (5.27×10^{-5} Btu/s-ft²-°R$^{1.33}$) for heated vertical flat surfaces and 0.00152 kW/m²-K$^{1.33}$ (6.11×10^{-5} Btu/s-ft²-°R$^{1.33}$) for heated horizontal flat surfaces [Holman, 1990].

A.8.3 Safety Margin

The safety margin may be considered a confidence measure of the calculated results. The safety margin differs from the LFS in that it measures the relative conservatism of the MEFS relative to the assumed parameters. The safety margin is determined by estimating the degree that various input parameter assumptions are bounding. A safety margin greater than one indicates that the calculated results bound the input uncertainty for the particular parameters.

Only parameters that could have a significant impact on the calculations are used to determine the safety margin. These include the following for the HEATING7 evaluations:

- Exposed surface boundary conditions.
- Unexposed target boundary conditions.

Other input parameters (material properties and geometric configuration) are well documented and are not subject to the sufficient uncertainty to include in the safety margin analysis. Because a detailed sensitivity analysis was not performed, the parameters that impact the safety margin and the safety margin itself are estimates. Section A.8.4 contains the safety margin input file templates for the conditions evaluated in this Section.

The exposed surface boundary conditions were assessed in the sensitivity analysis (absorptance) and in determining the LFS (increasing the flame emissivity). This section focuses on the unexposed surface boundary condition.

The analysis conservatively assumed that a junction box cable is essentially exposed on both sides: one surface perpendicular to the flame and parallel to the smoke layer during pre-immersion phase and one surface parallel to the flame and perpendicular to the smoke layer during pre-immersion phase. Although there is not truly an unexposed surface, a cable within a pump motor junction box would likely not be arranged as assumed; one surface would be in contact with additional cable insulation or splice material, or it would be exposed to a more or less ambient condition. Given this, two unexposed boundary conditions are considered: one where an adiabatic surface is applied that is a conservative approximation of the cable in contact with an insulation material, and one where the unexposed cable surface is exposed to ambient conditions. The results are summarized in Table A–14 for a second tier pump motor junction box exposed to a C-Pump lubricant exposure fire. The safety margin is determined from the difference in the target temperature increase assuming an initial temperature of 25°C (77°F).

In a similar manner, the analysis assumed a cable tray target would have an adiabatic unexposed surface to bound contact with an insulation. Since there are a large number of air gaps and contact with metal surfaces, this assumption is likely conservative. For this type of target, an adiabatic boundary condition is applied to the unexposed surface when determining the safety margin for the MEFS. The results are summarized in Table A–14. The safety margin is determined from the difference in the target temperature increase assuming an initial temperature of 25°C (77°F).

Table A–14. Safety Margin for HEATING7 Calculations

Target	Unexposed Boundary Condition	Peak Target Surface Temperature (°C [°F])		Safety Margin
		Baseline Condition	Modification	
Second Tier Motor Junction Box (C–Pump Fire)	Ambient	151 (304)	149 (300)	1.02
	Adiabatic		149 (300)	1.02
A–Train Cable Tray (E–Pump Fire)	Ambient	137 (279)	136 (277)	1.01

The safety margin is thus slightly greater than unity for the unexposed boundary conditions.

A.8.4 HEATING7 Input Files

A.8.4.1 MEFS HEATING Input File Template for Scenarios 2A and 2B – Pump Motor Junction Box Target

```
Motor Junction Box Target - Unit 1 C Pump Fire - MEFS
10000 9 0 1
REGIONS
1  2  0.0  0.00318  0  0  0  0
1  0  1  0  0  0  0  0
2  3  0.00318 0.00572  0  0  0  0
1  0  0  0  0  0  0  0
3  4  0.00572 0.015  0  0  0  0
1  0  0  0  0  0  0  0
4  3  0.015 0.01753  0  0  0  0
1  0  0  0  0  0  0  0
5  2  0.01753 0.02071 0  0  0  0
1  0  0  3  0  0  0  0
MATERIALS
1  GYPSUM   1.0   1.0     1.0    -1  -2   -3
2  STEEL    1.0   7800.0  1.0    -4   0   -5
3  PVC      0.17  1500.0  1.0     0   0   -15
4  COPPER   386.0 8954.0  383.0
INITIAL TEMPERATURES
1  25.0
BOUNDARY CONDITIONS
1   1   1.0  -504
0.0 4.54e-8  1.31 0.33 800.0 1
0.0 0.0 0.0 0.0 -500
3   1   1.0  -504
0.0 4.54e-8  1.52 0.33 800.0 1
0.0 0.0 0.0 0.0 -501
XGRID
  0.0  0.00318 0.00572 0.015 0.01753 0.02071
 5 6 7 6 5
```

```
TABULAR FUNCTIONS
*GYPSUM Type X k(T) from Sultan, 1996
1
    20.0  0.25,  99.5  0.25, 100.0  0.12,  399.5  0.12,
@  400.0  0.13, 600.0  0.20, 800.0  0.27, 1000.0  0.53,
*GYPSUM Type X density from Sultan, 1996
2
 20.0  698.0, 79.5 698.0, 80.0 576.0, 1000.0 576.0
*GYPSUM Type X cp(T) from Sultan, 1996
3
    20.0  1500.0,  77.5  1853.0,  78.0  1842.0,  84.5  2817.0,
@  85.0  2769.0,  96.5  5782.0,  97.0  5861.0, 123.5 18475.0,
@ 124.0 18479.0, 138.5  2573.0, 139.0  2006.0, 147.5  1114.0,
@ 148.0  1001.0, 372.5   716.0, 373.0   714.0, 429.5   714.0,
@ 430.0   715.0, 570.5   573.0, 571.0   571.0, 608.5   641.0,
@ 609.0   618.0, 661.5  2938.0, 662.0  3000.0, 669.5  3000.0,
@ 670.0  3070.0, 684.5   895.0, 685.0   571.0,1000.0   571.0
*Steel k(T) from Abrahams, 1978
4
    19.9 46.02,   38.0 46.02,  73.0 46.40,   149.0 45.73,
@  204.0 44.76,  260.0 43.84, 316.0 42.75,   371.0 41.04,
@  427.0 39.45,  482.0 37.82, 538.0 36.44,   593.0 34.73,
@  649.0 32.84,  677.0  32.1, 704.0 31.42,   732.0 30.92,
@  760.0 30.45,  788.0  30.0, 816.0 29.03,   843.0 27.15,
@  871.0 26.40,  899.0 26.73, 927.0 26.78, 1038.0 27.74,
@ 1149.0 29.15, 1288.0 30.38
*Steel cp(T) from Abrahams, 1978
5
    19.9  467.0,   38.0 471.0,   73.0 484.0,   149.0  501.0,
@  204.0  518.0,  260.0 536.0,  316.0 558.0,   371.0  580.0,
@  427.0  606.0,  482.0 641.0,  538.0 690.0,   593.0  736.0,
@  649.0  777.0,  677.0 810.0, 704.0 1098.0,   732.0 1410.0,
@  760.0 1012.0,  788.0 727.0,  816.0 568.0,   843.0  535.0,
@  871.0  522.0,  899.0 533.0,  927.0 568.0, 1038.0  584.0,
@ 1149.0  598.0, 1288.0 610.0
*PVC Cp
15
    18.0   950.0,  87.0  1457.0, 107.0 1569.0,  500.0  1569.0
30
    0.0   15897.0, 1100.0 15897.0, 1110.0 0.0, 1500.0 0.0
31
    0.0   4323.0, 1100.0 4323.0, 1110.0 0.0, 1500.0 0.0
* Flux: Cpump fire, adj. pump target, parallel
* +1.7 kW/m2 applied prior to layer reaching critical elevation
500
*See Figure A-17
* End Exposure
* Flux: Cpump fire, adj. pump target, perp
* +3.4 kW/m2 applied prior to layer reaching critical elevation
501
*See Figure A-17
* End Exposure
* Flux: Cpump fire, 2nd tier pump target, parallel
* +1.7 kW/m2 applied prior to layer reaching critical elevation
502
*See Figure A-17
* End Exposure
* Flux: Cpump fire, 2nd tier pump target, perp
* +3.4 kW/m2 applied prior to layer reaching critical elevation
503
*See Figure A-17
* End Exposure
* Temps - Cpump fire
* ambient until layer reaches critical elevation
504
*See Figure A-17
* End exposure
* Flux: A-pump fire, A-train cable tray target
* +1.7 kW/m2 applied prior to layer reaching critical elevation
510
```

```
*See Figure A-18
* End Exposure
* Flux: A-pump fire, adjacent pump target, paral
* +1.7 kW/m2 applied prior to layer reaching critical elevation
511
* See A-18
*   End Exposure
* Flux: A-pump fire, adjacent pump target, perp
* +3.4 kW/m2 applied prior to layer reaching critical elevation
512
*See Figure A-18
*   End Exposure
* Flux: A-pump fire, 2nd tier pump target, paral
* +1.7 kW/m2 applied prior to layer reaching critical elevation
513
*See Figure A-18
*   End Exposure
* Flux: A-pump fire, 2nd tier pump target, perp
* +3.4 kW/m2 applied prior to layer reaching critical elevation
514
*See Figure A-18
*   End Exposure
* Temps: A-pump
* ambient temps prior to layer reaching critical elevation
515
*See Figure A-14
NODES MONITORED
10  1  6 ·
TRANSIENT
2  1201.0
0.99 1.0e-4 2 1.0e-4 0.0 0.0 1 12 1
0.05 1.0 2.0 99999.0 0.0 0.0 0.01
%
```

A.8.4.2 MEFS Heating Input Template File for Scenario 2B – Cable Tray Target

```
Cable tray target - Unit 1 ABDE Pump Fire - MEFS
10000 9 0 1
REGIONS
1  2  0.0  0.00318  0  0  0  0
1  0  1  0  0  0  0  0
2  3  0.00318 0.00572  0  0  0  0
1  0  0  0  0  0  0  0
3  4  0.00572 0.015  0  0  0  0
1  0  0  0  0  0  0  0
4  3  0.015 0.01753  0  0  0  0
1  0  0  0  0  0  0  0
MATERIALS
1  GYPSUM   1.0   1.0      1.0    -1  -2   -3
2  STEEL    1.0   7800.0  1.0    -4   0   -5
3  PVC      0.17  1500.0  1.0     0   0   -15
4  COPPER   386.0 8954.0  383.0
INITIAL TEMPERATURES
1  25.0
BOUNDARY CONDITIONS
1   1   1.0  -515
0.0 4.54e-8  1.31 0.33 800.0  1
0.0 0.0 0.0 0.0 -510
XGRID
  0.0  0.00318 0.00572 0.015 0.01753
 5 6 7 6
TABULAR FUNCTIONS
*GYPSUM Type X k(T) from Sultan, 1996
1
    20.0  0.25,  99.5  0.25, 100.0  0.12,  399.5  0.12,
@  400.0  0.13, 600.0  0.20, 800.0  0.27, 1000.0  0.53,
*GYPSUM Type X density from Sultan, 1996
2
 20.0  698.0, 79.5 698.0, 80.0 576.0, 1000.0 576.0
```

```
*GYPSUM Type X cp(T) from Sultan, 1996
3
    20.0  1500.0,  77.5  1853.0,  78.0  1842.0,  84.5  2817.0,
@  85.0  2769.0,  96.5  5782.0,  97.0  5861.0, 123.5 18475.0,
@ 124.0 18479.0, 138.5  2573.0, 139.0  2006.0, 147.5  1114.0,
@ 148.0  1001.0, 372.5   716.0, 373.0   714.0, 429.5   714.0,
@ 430.0   715.0, 570.5   573.0, 571.0   571.0, 608.5   641.0,
@ 609.0   618.0, 661.5  2938.0, 662.0  3000.0, 669.5  3000.0,
@ 670.0  3070.0, 684.5   895.0, 685.0   571.0,1000.0   571.0
*Steel k(T) from Abrahams, 1978
4
    19.9 46.02,   38.0 46.02,  73.0 46.40,   149.0 45.73,
@  204.0 44.76,  260.0 43.84, 316.0 42.75,   371.0 41.04,
@  427.0 39.45,  482.0 37.82, 538.0 36.44,   593.0 34.73,
@  649.0 32.84,  677.0  32.1, 704.0 31.42,   732.0 30.92,
@  760.0 30.45,  788.0  30.0, 816.0 29.03,   843.0 27.15,
@  871.0 26.40,  899.0 26.73, 927.0 26.78, 1038.0 27.74,
@ 1149.0 29.15, 1288.0 30.38
*Steel cp(T) from Abrahams, 1978
5
    19.9  467.0,   38.0 471.0,   73.0 484.0,   149.0  501.0,
@  204.0  518.0,  260.0 536.0,  316.0 558.0,   371.0  580.0,
@  427.0  606.0,  482.0 641.0,  538.0 690.0,   593.0  736.0,
@  649.0  777.0,  677.0 810.0, 704.0 1098.0,   732.0 1410.0,
@  760.0 1012.0,  788.0 727.0,  816.0 568.0,   843.0  535.0,
@  871.0  522.0,  899.0 533.0,  927.0 568.0, 1038.0  584.0,
@ 1149.0  598.0, 1288.0 610.0
*PVC Cp
15
    18.0   950.0,  87.0  1457.0, 107.0 1569.0,   500.0  1569.0
35
    0.0    12640.0, 546.0 12640.0,  547.0 0.0,  1000.0 0.0
* Flux: A-pump fire, A-train cable tray target
* +1.7 kW/m2 applied prior to layer reaching critical elevation
510
*See Figure A-17
* End exposure
* Temps: A-pump
* ambient temps prior to layer reaching critical elevation
515
*See Figure A-14
NODES MONITORED
10  1  6
TRANSIENT
2  1200.0
0.99 1.0e-4 2 1.0e-4 0.0 0.0 1 12 1
0.05 1.0 2.0 99999.0 0.0 0.0 0.01
%
```

A.8.4.3 Sensitivity Analysis HEATING Input File Template – Scenario 1

```
NECorner - Sensitivity Template for Oil-Soaked Class A fires 24 Ga Cable Tray
10000 9 0 1
REGIONS
1  2  0.0026  0.00318  0  0  0  0
1  0  1  0  0  0  0  0
2  3  0.00318 0.00572  0  0  0  0
1  0  0  0  0  0  0  0
*3  4  0.00572 0.015  0  0  0  0
*1  0  0  0  0  0  0  0
*4  3  0.015 0.01753  0  0  0  0
*1  0  0  0  0  0  0  0
MATERIALS
1  GYPSUM   1.0    1.0     1.0    -1  -2   -3
2  STEEL    1.0    7800.0  1.0    -4   0   -5
3  PVC      0.17   1500.0  1.0     0   0   -15
4  COPPER   386.0  8954.0  383.0
INITIAL TEMPERATURES
1  20.0
```

```
BOUNDARY CONDITIONS
*Vary exposure temperature
1   1  650.0
10.0 3.40e-8  0.0 1.0
XGRID
*  0.0026  0.00318 0.00572 0.015 0.01753
* 2 6 7 6
 0.0026  0.00318 0.00572
 2 6
TABULAR FUNCTIONS
*GYPSUM Type X k(T) from Sultan, 1996
1
    20.0  0.25,  99.5  0.25, 100.0  0.12,  399.5  0.12,
@  400.0  0.13, 600.0  0.20, 800.0  0.27, 1000.0  0.53,
*GYPSUM Type X density from Sultan, 1996
2
 20.0  698.0, 79.5 698.0, 80.0 576.0,`1000.0 576.0
*GYPSUM Type X cp(T) from Sultan, 1996
3
    20.0  1500.0,  77.5  1853.0,  78.0  1842.0,  84.5  2817.0,
@  85.0  2769.0,  96.5  5782.0,  97.0  5861.0, 123.5 18475.0,
@ 124.0 18479.0, 138.5  2573.0, 139.0  2006.0, 147.5  1114.0,
@ 148.0  1001.0, 372.5   716.0, 373.0   714.0, 429.5   714.0,
@ 430.0   715.0, 570.5   573.0, 571.0   571.0, 608.5   641.0,
@ 609.0   618.0, 661.5  2938.0, 662.0  3000.0, 669.5  3000.0,
@ 670.0  3070.0, 684.5   895.0, 685.0   571.0,1000.0   571.0
*Steel k(T) from Abrahams, 1978
4
    19.9 46.02,   38.0 46.02,  73.0 46.40,  149.0 45.73,
@  204.0 44.76,  260.0 43.84, 316.0 42.75,  371.0 41.04,
@  427.0 39.45,  482.0 37.82, 538.0 36.44,  593.0 34.73,
@  649.0 32.84,  677.0  32.1, 704.0 31.42,  732.0 30.92,
@  760.0 30.45,  788.0  30.0, 816.0 29.03,  843.0 27.15,
@  871.0 26.40,  899.0 26.73, 927.0 26.78, 1038.0 27.74,
@ 1149.0 29.15, 1288.0 30.38
*Steel cp(T) from Abrahams, 1978
5
    19.9  467.0,   38.0 471.0,   73.0 484.0,  149.0  501.0,
@  204.0  518.0,  260.0 536.0,  316.0 558.0,  371.0  580.0,
@  427.0  606.0,  482.0 641.0,  538.0 690.0,  593.0  736.0,
@  649.0  777.0,  677.0 810.0, 704.0 1098.0,  732.0 1410.0,
@  760.0 1012.0,  788.0 727.0,  816.0 568.0,  843.0  535.0,
@  871.0  522.0,  899.0 533.0,  927.0 568.0, 1038.0  584.0,
@ 1149.0  598.0, 1288.0 610.0
*PVC Cp
15
    18.0   950.0,  87.0  1457.0, 107.0 1569.0,  500.0  1569.0
35
    0.0    9480.00, 546.0 9480.0,  547.0 0.0,  1000.0 0.0
NODES MONITORED
10  1  3
TRANSIENT
*Vary exposure duration
2  86.0
0.99 1.0e-4 2 1.0e-4 0.0 0.0 1 12 1
0.05 1.0 2.0 99999.0 0.0 0.0 0.01
%
```

A.8.4.4 Sensitivity Analysis HEATING Input File Template for Scenarios 2A and 2B – Pump Motor Junction Box Target

```
Scenarios 2A2B - motor junction box target template - sensitivity
10000 9 0 1
REGIONS
1  2  0.0  0.00318  0  0  0  0
1  0  1  0  0  0  0  0
2  3  0.00318 0.00572  0  0  0  0
1  0  0  0  0  0  0  0
```

```
3  4  0.00572 0.015  0  0  0  0
1  0  0  0  0  0  0  0
4  3  0.015 0.01753  0  0  0  0
1  0  0  0  0  0  0  0
5  2  0.01753 0.02071 0  0  0  0
1  0  0  3  0  0  0  0
MATERIALS
1  GYPSUM   1.0   1.0     1.0    -1  -2   -3
2  STEEL    1.0   7800.0  1.0    -4   0   -5
3  PVC      0.17  1500.0  1.0     0   0   -15
4  COPPER   386.0 8954.0  383.0
INITIAL TEMPERATURES
1  25.0
BOUNDARY CONDITIONS
1  1  25.0
0.0 4.54e-8  1.31 0.33 0.8 1
0.0 0.0 0.0 0.0 -500
3  1  25.0
0.0 4.54e-8  1.52 0.33 0.8 1
0.0 0.0 0.0 0.0 -510
XGRID
  0.0  0.00318 0.00572 0.015 0.01753 0.02071
 5 6 7 6 5
TABULAR FUNCTIONS
*GYPSUM Type X k(T) from Sultan, 1996
1
    20.0  0.25,  99.5  0.25, 100.0  0.12,  399.5  0.12,
@  400.0  0.13, 600.0  0.20, 800.0  0.27, 1000.0  0.53,
*GYPSUM Type X density from Sultan, 1996
2
 20.0  698.0, 79.5 698.0, 80.0 576.0, 1000.0 576.0
*GYPSUM Type X cp(T) from Sultan, 1996
3
    20.0  1500.0,  77.5  1853.0,  78.0  1842.0,  84.5  2817.0,
@  85.0  2769.0,  96.5  5782.0,  97.0  5861.0, 123.5 18475.0,
@ 124.0 18479.0, 138.5  2573.0, 139.0  2006.0, 147.5  1114.0,
@ 148.0  1001.0, 372.5   716.0, 373.0   714.0, 429.5   714.0,
@ 430.0   715.0, 570.5   573.0, 571.0   571.0, 608.5   641.0,
@ 609.0   618.0, 661.5  2938.0, 662.0  3000.0, 669.5  3000.0,
@ 670.0  3070.0, 684.5   895.0, 685.0   571.0,1000.0   571.0
*Steel k(T) from Abrahams, 1978
4
    19.9 46.02,   38.0 46.02,  73.0 46.40,   149.0 45.73,
@  204.0 44.76,  260.0 43.84, 316.0 42.75,   371.0 41.04,
@  427.0 39.45,  482.0 37.82, 538.0 36.44,   593.0 34.73,
@  649.0 32.84,  677.0  32.1, 704.0 31.42,   732.0 30.92,
@  760.0 30.45,  788.0  30.0, 816.0 29.03,   843.0 27.15,
@  871.0 26.40,  899.0 26.73, 927.0 26.78, 1038.0 27.74,
@ 1149.0 29.15, 1288.0 30.38
*Steel cp(T) from Abrahams, 1978
5
    19.9  467.0,    38.0 471.0,   73.0 484.0,   149.0  501.0,
@  204.0  518.0,   260.0 536.0,  316.0 558.0,   371.0  580.0,
@  427.0  606.0,   482.0 641.0,  538.0 690.0,   593.0  736.0,
@  649.0  777.0,   677.0 810.0, 704.0 1098.0,   732.0 1410.0,
@  760.0 1012.0,   788.0 727.0,  816.0 568.0,   843.0  535.0,
@  871.0  522.0,   899.0 533.0,  927.0 568.0,  1038.0  584.0,
@ 1149.0  598.0, 1288.0 610.0
*PVC Cp
15
    18.0   950.0,  87.0  1457.0, 107.0 1569.0,  500.0  1569.0
30
    0.0   15897.0, 1100.0 15897.0, 1110.0 0.0, 1500.0 0.0
31
    0.0   4323.0, 1100.0 4323.0, 1110.0 0.0, 1500.0 0.0
* Flux: Cpump fire, adj. pump target, parallel
* +0.0 kW/m2 applied from overhead smoke layer
500
     0.00  45000.0, 1098.0 45000.0, 1099.0 0.0, 1201.0 0.0
* Flux: Cpump fire, 2nd tier pump target, parallel
```

```
* +0.0 kW/m2 applied from overhead smoke layer
501
    0.00  19100.0, 1098.0 19100.0, 1099.0 0.0, 1201.0 0.0
* Flux: ABDEpump fire, adj. pump target, parallel
* +1.7 kW/m2 applied from overhead smoke layer
502
    0.00  46200.0, 546.0 46200.0, 547.0 0.0, 1201.0 0.0
* Flux: ABDEpump fire, 2nd tier pump target, parallel
* +1.7 kW/m2 applied from overhead smoke layer
503
    0.00  20600.0, 546.0 20600.0, 547.0 0.0, 1201.0 0.0
* Flux: Cpump fire, adj. pump target, parallel
* +0.0 kW/m2 applied from overhead smoke layer
510
    0.00  25900.0, 1098.0 25900.0, 1099.0 0.0, 1201.0 0.0
* Flux: Cpump fire, 2nd tier pump target, parallel
* +0.0 kW/m2 applied from overhead smoke layer
511
    0.00  5100.0, 1098.0 5100.0, 1099.0 0.0, 1201.0 0.0
* Flux: ABDEpump fire, adj. pump target, parallel
* +3.4 kW/m2 applied from overhead smoke layer
512
    0.00  29000.0, 546.0 29000.0, 547.0 0.0, 1201.0 0.0
* Flux: ABDEpump fire, 2nd tier pump target, parallel
* +3.4 kW/m2 applied from overhead smoke layer
513
    0.00  8400.0, 546.0 8400.0, 547.0 0.0, 1201.0 0.0
NODES MONITORED
10  1  6
TRANSIENT
2  1201.0
0.99 1.0e-4 2 1.0e-4 0.0 0.0 1 12 1
0.05 1.0 2.0 99999.0 0.0 0.0 0.01
%
```

A.8.4.5 Sensitivity Analysis HEATING Input File Template for Scenario 2B – Cable Tray Target

```
Scenario 2B Cable tray target - sensitivity analysis template
10000 9 0 1
REGIONS
1  2  0.0  0.00318  0  0  0  0
1  0  1  0  0  0  0  0
2  3  0.00318 0.00572  0  0  0  0
1  0  0  0  0  0  0  0
3  4  0.00572 0.015  0  0  0  0
1  0  0  0  0  0  0  0
4  3  0.015 0.01753  0  0  0  0
1  0  0  0  0  0  0  0
MATERIALS
1  GYPSUM    1.0   1.0     1.0    -1  -2   -3
2  STEEL     1.0   7800.0  1.0    -4   0   -5
3  PVC       0.17  1500.0  1.0     0   0   -15
4  COPPER    386.0 8954.0  383.0
INITIAL TEMPERATURES
1  25.0
BOUNDARY CONDITIONS
1   1   25.0
0.0 4.54e-8  1.31 0.33  0.8  1
0.0 0.0 0.0 0.0 -510
XGRID
  0.0  0.00318 0.00572 0.015 0.01753
 5 6 7 6
TABULAR FUNCTIONS
*GYPSUM Type X k(T) from Sultan, 1996
1
   20.0  0.25,  99.5  0.25, 100.0  0.12,  399.5  0.12,
@  400.0  0.13, 600.0  0.20, 800.0  0.27, 1000.0  0.53,
```

```
*GYPSUM Type X density from Sultan, 1996
2
 20.0  698.0, 79.5 698.0, 80.0 576.0, 1000.0 576.0
*GYPSUM Type X cp(T) from Sultan, 1996
3
    20.0  1500.0,  77.5  1853.0,  78.0  1842.0,  84.5  2817.0,
@  85.0  2769.0,  96.5  5782.0,  97.0  5861.0, 123.5 18475.0,
@ 124.0 18479.0, 138.5  2573.0, 139.0  2006.0, 147.5  1114.0,
@ 148.0  1001.0, 372.5   716.0, 373.0   714.0, 429.5   714.0,
@ 430.0   715.0, 570.5   573.0, 571.0   571.0, 608.5   641.0,
@ 609.0   618.0, 661.5  2938.0, 662.0  3000.0, 669.5  3000.0,
@ 670.0  3070.0, 684.5   895.0, 685.0   571.0,1000.0   571.0
*Steel k(T) from Abrahams, 1978
4
    19.9 46.02,   38.0 46.02,  73.0 46.40,   149.0 45.73,
@  204.0 44.76,  260.0 43.84, 316.0 42.75,   371.0 41.04,
@  427.0 39.45,  482.0 37.82, 538.0 36.44,   593.0 34.73,
@  649.0 32.84,  677.0  32.1, 704.0 31.42,   732.0 30.92,
@  760.0 30.45,  788.0  30.0, 816.0 29.03,   843.0 27.15,
@  871.0 26.40,  899.0 26.73, 927.0 26.78,  1038.0 27.74,
@ 1149.0 29.15, 1288.0 30.38
*Steel cp(T) from Abrahams, 1978
5
    19.9  467.0,    38.0 471.0,    73.0 484.0,   149.0  501.0,
@  204.0  518.0,   260.0 536.0,   316.0 558.0,   371.0  580.0,
@  427.0  606.0,   482.0 641.0,   538.0 690.0,   593.0  736.0,
@  649.0  777.0,   677.0 810.0,  704.0 1098.0,   732.0 1410.0,
@  760.0 1012.0,   788.0 727.0,   816.0 568.0,   843.0  535.0,
@  871.0  522.0,   899.0 533.0,   927.0 568.0,  1038.0  584.0,
@ 1149.0  598.0, 1288.0 610.0
*PVC Cp
15
    18.0   950.0,  87.0  1457.0, 107.0 1569.0,  500.0  1569.0
35
    0.0    12640.0, 546.0 12640.0,  547.0 0.0,  1000.0 0.0
* Flux: A-pump fire, A-train cable tray target
* +1.7 kW/m2 applied prior to layer reaching critical elevation
510
  0.0  17400.0,  546.0  17400.0,  547.0  0.0,  1201.0  0.0
NODES MONITORED
10  1  6
TRANSIENT
2  1200.0
0.99 1.0e-4 2 1.0e-4 0.0 0.0 1 12 1
0.05 1.0 2.0 99999.0 0.0 0.0 0.01
%
```

A.8.4.6 LFS HEATING Input File Template for Scenarios 2A and 2B – Pump Motor Junction Box Target

```
Scenarios 2A2B - Pump Motor Junction box target - LFS template
10000 9 0 1
REGIONS
1  2  0.0  0.00318  0  0  0  0
1  0  1  0  0  0  0  0
2  3  0.00318 0.00572  0  0  0  0
1  0  0  0  0  0  0  0
3  4  0.00572 0.015  0  0  0  0
1  0  0  0  0  0  0  0
4  3  0.015 0.01753  0  0  0  0
1  0  0  0  0  0  0  0
5  2  0.01753 0.02071 0  0  0  0
1  0  0  3  0  0  0  0
MATERIALS
1  GYPSUM   1.0   1.0     1.0    -1  -2   -3
2  STEEL    1.0   7800.0  1.0    -4   0   -5
3  PVC      0.17  1500.0  1.0     0   0   -15
4  COPPER   386.0 8954.0  383.0
```

```
INITIAL TEMPERATURES
1  25.0
BOUNDARY CONDITIONS
* LFS Determination: Increase flux multiplier until target reaches 330
1   1   1.0  -504
0.0 4.54e-8  1.31 0.33 960.0 1
0.0 0.0 0.0 0.0 -500
3   1   1.0  -504
0.0 4.54e-8  1.52 0.33 960.0 1
0.0 0.0 0.0 0.0 -501
XGRID
  0.0  0.00318 0.00572 0.015 0.01753 0.02071
 5 6 7 6 5
TABULAR FUNCTIONS
*GYPSUM Type X k(T) from Sultan, 1996
1
    20.0  0.25,  99.5  0.25, 100.0  0.12,  399.5  0.12,
@  400.0  0.13, 600.0  0.20, 800.0  0.27, 1000.0  0.53,
*GYPSUM Type X density from Sultan, 1996
2
 20.0  698.0, 79.5 698.0, 80.0 576.0, 1000.0 576.0
*GYPSUM Type X cp(T) from Sultan, 1996
3
    20.0  1500.0,  77.5  1853.0,  78.0  1842.0,  84.5  2817.0,
@  85.0  2769.0,  96.5  5782.0,  97.0  5861.0, 123.5 18475.0,
@ 124.0 18479.0, 138.5  2573.0, 139.0  2006.0, 147.5  1114.0,
@ 148.0  1001.0, 372.5   716.0, 373.0   714.0, 429.5   714.0,
@ 430.0   715.0, 570.5   573.0, 571.0   571.0, 608.5   641.0,
@ 609.0   618.0, 661.5  2938.0, 662.0  3000.0, 669.5  3000.0,
@ 670.0  3070.0, 684.5   895.0, 685.0   571.0,1000.0   571.0
*Steel k(T) from Abrahams, 1978
4
    19.9 46.02,   38.0 46.02,  73.0 46.40,  149.0 45.73,
@  204.0 44.76,  260.0 43.84, 316.0 42.75,  371.0 41.04,
@  427.0 39.45,  482.0 37.82, 538.0 36.44,  593.0 34.73,
@  649.0 32.84,  677.0  32.1, 704.0 31.42,  732.0 30.92,
@  760.0 30.45,  788.0  30.0, 816.0 29.03,  843.0 27.15,
@  871.0 26.40,  899.0 26.73, 927.0 26.78, 1038.0 27.74,
@ 1149.0 29.15, 1288.0 30.38
*Steel cp(T) from Abrahams, 1978
5
    19.9  467.0,   38.0 471.0,   73.0 484.0,  149.0  501.0,
@  204.0  518.0,  260.0 536.0,  316.0 558.0,  371.0  580.0,
@  427.0  606.0,  482.0 641.0,  538.0 690.0,  593.0  736.0,
@  649.0  777.0,  677.0 810.0, 704.0 1098.0,  732.0 1410.0,
@  760.0 1012.0,  788.0 727.0,  816.0 568.0,  843.0  535.0,
@  871.0  522.0,  899.0 533.0,  927.0 568.0, 1038.0  584.0,
@ 1149.0  598.0, 1288.0 610.0
*PVC Cp
15
    18.0   950.0,  87.0  1457.0, 107.0 1569.0,  500.0  1569.0
30
    0.0   15897.0, 1100.0 15897.0, 1110.0 0.0, 1500.0 0.0
31
    0.0   4323.0, 1100.0 4323.0, 1110.0 0.0, 1500.0 0.0
* Flux: Cpump fire, adj. pump target, parallel
* +1.7 kW/m2 applied prior to layer reaching critical elevation
500
*See Figure A-17
* End Exposure
* Flux: Cpump fire, adj. pump target, perp
* +3.4 kW/m2 applied prior to layer reaching critical elevation
501
*See Figure A-17
* End Exposure
* Flux: Cpump fire, 2nd tier pump target, parallel
* +1.7 kW/m2 applied prior to layer reaching critical elevation
502
*See Figure A-17
* End Exposure
```

```
* Flux: Cpump fire, 2nd tier pump target, perp
* +3.4 kW/m2 applied prior to layer reaching critical elevation
503
*See Figure A-17
* End Exposure
* Temps - Cpump fire
* ambient until layer reaches critical elevation
504
*See Figure A-17
* End exposure
* Flux: A-pump fire, A-train cable tray target
* +1.7 kW/m2 applied prior to layer reaching critical elevation
510
*See Figure A-18
* End Exposure
* Flux: A-pump fire, adjacent pump target, paral
* +1.7 kW/m2 applied prior to layer reaching critical elevation
511
* See A-18
*   End Exposure
* Flux: A-pump fire, adjacent pump target, perp
* +3.4 kW/m2 applied prior to layer reaching critical elevation
512
*See Figure A-18
*   End Exposure
* Flux: A-pump fire, 2nd tier pump target, paral
* +1.7 kW/m2 applied prior to layer reaching critical elevation
513
*See Figure A-18
*   End Exposure
* Flux: A-pump fire, 2nd tier pump target, perp
* +3.4 kW/m2 applied prior to layer reaching critical elevation
514
*See Figure A-18
*   End Exposure
* Temps: A-pump
* ambient temps prior to layer reaching critical elevation
515
*See Figure A-14
NODES MONITORED
10  1  6
TRANSIENT
2  1201.0
0.99 1.0e-4 2 1.0e-4 0.0 0.0 1 12 1
0.05 1.0 2.0 99999.0 0.0 0.0 0.01
%
```

A.8.4.7 LFS HEATING Input File Template for Scenarios 2B – Cable Tray Target

```
Scenario 2B - Cable Tray Target - LFS Template
10000 9 0 1
REGIONS
1  2  0.0  0.00318  0  0  0  0
1  0  1  0  0  0  0  0
2  3  0.00318 0.00572  0  0  0  0
1  0  0  0  0  0  0  0
3  4  0.00572 0.015  0  0  0  0
1  0  0  0  0  0  0  0
4  3  0.015 0.01753  0  0  0  0
1  0  0  0  0  0  0  0
MATERIALS
1  GYPSUM   1.0    1.0     1.0    -1  -2   -3
2  STEEL    1.0    7800.0  1.0    -4   0   -5
3  PVC      0.17   1500.0  1.0     0   0   -15
4  COPPER   386.0  8954.0  383.0
INITIAL TEMPERATURES
1  25.0
BOUNDARY CONDITIONS
* Determin LFS by increasing flux multiplier until target reaches 330C
```

```
1   1   1.0  -515
0.0 4.54e-8  1.31 0.33 2920.0  1
0.0 0.0 0.0 0.0 -510
XGRID
  0.0  0.00318 0.00572 0.015 0.01753
 5 6 7 6
TABULAR FUNCTIONS
*GYPSUM Type X k(T) from Sultan, 1996
1
    20.0  0.25,  99.5  0.25, 100.0  0.12,  399.5  0.12,
@  400.0  0.13, 600.0  0.20, 800.0  0.27, 1000.0  0.53,
*GYPSUM Type X density from Sultan, 1996
2
 20.0  698.0, 79.5 698.0, 80.0 576.0, 1000.0 576.0
*GYPSUM Type X cp(T) from Sultan, 1996
3
    20.0  1500.0,  77.5  1853.0,  78.0  1842.0,  84.5  2817.0,
@  85.0  2769.0,  96.5  5782.0,  97.0  5861.0, 123.5 18475.0,
@ 124.0 18479.0, 138.5  2573.0, 139.0  2006.0, 147.5  1114.0,
@ 148.0  1001.0, 372.5   716.0, 373.0   714.0, 429.5   714.0,
@ 430.0   715.0, 570.5   573.0, 571.0   571.0, 608.5   641.0,
@ 609.0   618.0, 661.5  2938.0, 662.0  3000.0, 669.5  3000.0,
@ 670.0  3070.0, 684.5   895.0, 685.0   571.0,1000.0   571.0
*Steel k(T) from Abrahams, 1978
4
    19.9 46.02,   38.0 46.02,  73.0 46.40,   149.0 45.73,
@  204.0 44.76,  260.0 43.84, 316.0 42.75,   371.0 41.04,
@  427.0 39.45,  482.0 37.82, 538.0 36.44,   593.0 34.73,
@  649.0 32.84,  677.0  32.1, 704.0 31.42,   732.0 30.92,
@  760.0 30.45,  788.0  30.0, 816.0 29.03,   843.0 27.15,
@  871.0 26.40,  899.0 26.73, 927.0 26.78, 1038.0 27.74,
@ 1149.0 29.15, 1288.0 30.38
*Steel cp(T) from Abrahams, 1978
5
    19.9  467.0,   38.0 471.0,   73.0 484.0,  149.0  501.0,
@  204.0  518.0,  260.0 536.0,  316.0 558.0,  371.0  580.0,
@  427.0  606.0,  482.0 641.0,  538.0 690.0,  593.0  736.0,
@  649.0  777.0,  677.0 810.0, 704.0 1098.0,  732.0 1410.0,
@  760.0 1012.0,  788.0 727.0,  816.0 568.0,  843.0  535.0,
@  871.0  522.0,  899.0 533.0,  927.0 568.0, 1038.0  584.0,
@ 1149.0  598.0, 1288.0 610.0
*PVC Cp
15
    18.0   950.0,  87.0  1457.0, 107.0 1569.0,  500.0  1569.0
35
    0.0    12640.0, 546.0 12640.0,  547.0 0.0,  1000.0 0.0
* Flux: A-pump fire, A-train cable tray target
* +1.7 kW/m2 applied prior to layer reaching critical elevation
510
*See Figure A-17
* End exposure
* Temps: A-pump
* ambient temps prior to layer reaching critical elevation
515
*See Figure A-14
NODES MONITORED
10  1  6
TRANSIENT
2  1200.0
0.99 1.0e-4 2 1.0e-4 0.0 0.0 1 12 1
0.05 1.0 2.0 99999.0 0.0 0.0 0.01
%
```

A.8.4.8 Safety Margin HEATING Input File Template for Scenario 2A – Pump Motor Junction Box Target

```
Scenario 2A - Pump Motor Junction box target - Safety margin template
10000 9 0 1
REGIONS
1  2  0.0  0.00318  0  0  0  0
1  0  1  0  0  0  0  0
2  3  0.00318 0.00572  0  0  0  0
1  0  0  0  0  0  0  0
3  4  0.00572 0.015  0  0  0  0
1  0  0  0  0  0  0  0
4  3  0.015 0.01753  0  0  0  0
*Adiabatic
1  0  0  0  0  0  0  0
*Ambient
*1  0  0  5  0  0  0  0
*5  2  0.01753 0.02071 0  0  0  0
*1  0  0  3  0  0  0  0
MATERIALS
1  GYPSUM   1.0   1.0     1.0    -1  -2   -3
2  STEEL    1.0   7800.0  1.0    -4   0   -5
3  PVC      0.17  1500.0  1.0     0   0   -15
4  COPPER   386.0 8954.0  383.0
INITIAL TEMPERATURES
1  25.0
BOUNDARY CONDITIONS
1   1   1.0  -504
0.0 4.54e-8  1.31 0.33 800.0 1
0.0 0.0 0.0 0.0 -502
3   1   1.0  -504
0.0 4.54e-8  1.52 0.33 800.0 1
0.0 0.0 0.0 0.0 -503
*Ambient
5   1   25.0
0.0  4.54e-8  1.31  0.33
XGRID
*  0.0  0.00318 0.00572 0.015 0.01753 0.02071
* 5 6 7 6 5
  0.0  0.00318 0.00572 0.015 0.01753
 5 6 7 6
TABULAR FUNCTIONS
*GYPSUM Type X k(T) from Sultan, 1996
1
    20.0  0.25,  99.5  0.25, 100.0  0.12,  399.5  0.12,
@  400.0  0.13, 600.0  0.20, 800.0  0.27, 1000.0  0.53,
*GYPSUM Type X density from Sultan, 1996
2
 20.0  698.0, 79.5 698.0, 80.0 576.0, 1000.0 576.0
*GYPSUM Type X cp(T) from Sultan, 1996
3
    20.0  1500.0,  77.5  1853.0,  78.0  1842.0,  84.5  2817.0,
@  85.0  2769.0,  96.5  5782.0,  97.0  5861.0, 123.5 18475.0,
@ 124.0 18479.0, 138.5  2573.0, 139.0  2006.0, 147.5  1114.0,
@ 148.0  1001.0, 372.5   716.0, 373.0   714.0, 429.5   714.0,
@ 430.0   715.0, 570.5   573.0, 571.0   571.0, 608.5   641.0,
@ 609.0   618.0, 661.5  2938.0, 662.0  3000.0, 669.5  3000.0,
@ 670.0  3070.0, 684.5   895.0, 685.0   571.0,1000.0   571.0
*Steel k(T) from Abrahams, 1978
4
    19.9 46.02,   38.0 46.02,  73.0 46.40,  149.0 45.73,
@  204.0 44.76,  260.0 43.84, 316.0 42.75,  371.0 41.04,
@  427.0 39.45,  482.0 37.82, 538.0 36.44,  593.0 34.73,
@  649.0 32.84,  677.0  32.1, 704.0 31.42,  732.0 30.92,
@  760.0 30.45,  788.0  30.0, 816.0 29.03,  843.0 27.15,
@  871.0 26.40,  899.0 26.73, 927.0 26.78, 1038.0 27.74,
@ 1149.0 29.15, 1288.0 30.38
*Steel cp(T) from Abrahams, 1978
```

```
5
   19.9  467.0,    38.0 471.0,    73.0 484.0,   149.0  501.0,
@  204.0  518.0,   260.0 536.0,   316.0 558.0,   371.0  580.0,
@  427.0  606.0,   482.0 641.0,   538.0 690.0,   593.0  736.0,
@  649.0  777.0,   677.0 810.0,  704.0 1098.0,   732.0 1410.0,
@  760.0 1012.0,   788.0 727.0,   816.0 568.0,   843.0  535.0,
@  871.0  522.0,   899.0 533.0,   927.0 568.0,  1038.0  584.0,
@ 1149.0  598.0,  1288.0 610.0
*PVC Cp
15
   18.0   950.0,  87.0  1457.0, 107.0 1569.0,  500.0  1569.0
30
   0.0   15897.0, 1100.0 15897.0, 1110.0 0.0, 1500.0 0.0
31
   0.0   4323.0, 1100.0 4323.0, 1110.0 0.0, 1500.0 0.0
* Flux: Cpump fire, adj. pump target, parallel
* +1.7 kW/m2 applied prior to layer reaching critical elevation
500
*See Figure A-17
* End Exposure
* Flux: Cpump fire, adj. pump target, perp
* +3.4 kW/m2 applied prior to layer reaching critical elevation
501
*See Figure A-17
* End Exposure
* Flux: Cpump fire, 2nd tier pump target, parallel
* +1.7 kW/m2 applied prior to layer reaching critical elevation
502
*See Figure A-17
* End Exposure
* Flux: Cpump fire, 2nd tier pump target, perp
* +3.4 kW/m2 applied prior to layer reaching critical elevation
503
*See Figure A-17
* End Exposure
* Temps - Cpump fire
* ambient until layer reaches critical elevation
504
*See Figure A-17
* End exposure
* Flux: A-pump fire, A-train cable tray target
* +1.7 kW/m2 applied prior to layer reaching critical elevation
510
*See Figure A-18
* End Exposure
* Flux: A-pump fire, adjacent pump target, paral
* +1.7 kW/m2 applied prior to layer reaching critical elevation
511
* See A-18
*   End Exposure
* Flux: A-pump fire, adjacent pump target, perp
* +3.4 kW/m2 applied prior to layer reaching critical elevation
512
*See Figure A-18
*   End Exposure
* Flux: A-pump fire, 2nd tier pump target, paral
* +1.7 kW/m2 applied prior to layer reaching critical elevation
513
*See Figure A-18
*   End Exposure
* Flux: A-pump fire, 2nd tier pump target, perp
* +3.4 kW/m2 applied prior to layer reaching critical elevation
514
*See Figure A-18
*   End Exposure
* Temps: A-pump
* ambient temps prior to layer reaching critical elevation
515
*See Figure A-14
NODES MONITORED
```

```
10  1  6
TRANSIENT
2  1201.0
0.99 1.0e-4 2 1.0e-4 0.0 0.0 1 12 1
0.05 1.0 2.0 99999.0 0.0 0.0 0.01
%
```

A.8.4.9 LFS HEATING Input File Template for Scenarios 2B – Cable Tray Target

```
Scenario 2B - Cable Tray Target - Safety Margin Template
10000 9 0 1
REGIONS
1  2  0.0  0.00318  0  0  0  0
1  0  1  0  0  0  0  0
2  3  0.00318 0.00572  0  0  0  0
1  0  0  0  0  0  0  0
3  4  0.00572 0.015  0  0  0  0
1  0  0  0  0  0  0  0
4  3  0.015 0.01753  0  0  0  0
1  0  0  5  0  0  0  0
MATERIALS
1  GYPSUM   1.0    1.0      1.0     -1  -2   -3
2  STEEL    1.0    7800.0  1.0     -4   0   -5
3  PVC      0.17   1500.0  1.0      0   0   -15
4  COPPER   386.0 8954.0  383.0
INITIAL TEMPERATURES
1  25.0
BOUNDARY CONDITIONS
1  1   1.0  -515
0.0 4.54e-8  1.31 0.33 800.0  1
0.0 0.0 0.0 0.0 -510
*Ambient boundary condition
5  1   25.0
0.0  4.54e-8  1.31  0.33
XGRID
  0.0  0.00318 0.00572 0.015 0.01753
 5 6 7 6
TABULAR FUNCTIONS
*GYPSUM Type X k(T) from Sultan, 1996
1
    20.0  0.25,  99.5  0.25, 100.0  0.12,  399.5  0.12,
@  400.0  0.13, 600.0  0.20, 800.0  0.27, 1000.0  0.53,
*GYPSUM Type X density from Sultan, 1996
2
 20.0  698.0, 79.5 698.0, 80.0 576.0, 1000.0 576.0
*GYPSUM Type X cp(T) from Sultan, 1996
3
    20.0  1500.0,  77.5  1853.0,  78.0  1842.0,  84.5  2817.0,
@  85.0  2769.0,  96.5  5782.0,  97.0  5861.0, 123.5 18475.0,
@ 124.0 18479.0, 138.5  2573.0, 139.0  2006.0, 147.5  1114.0,
@ 148.0  1001.0, 372.5   716.0, 373.0   714.0, 429.5   714.0,
@ 430.0   715.0, 570.5   573.0, 571.0   571.0, 608.5   641.0,
@ 609.0   618.0, 661.5  2938.0, 662.0  3000.0, 669.5  3000.0,
@ 670.0  3070.0, 684.5   895.0, 685.0   571.0,1000.0   571.0
*Steel k(T) from Abrahams, 1978
4
    19.9 46.02,   38.0 46.02,  73.0 46.40,  149.0 45.73,
@  204.0 44.76,  260.0 43.84, 316.0 42.75,  371.0 41.04,
@  427.0 39.45,  482.0 37.82, 538.0 36.44,  593.0 34.73,
@  649.0 32.84,  677.0  32.1, 704.0 31.42,  732.0 30.92,
@  760.0 30.45,  788.0  30.0, 816.0 29.03,  843.0 27.15,
@  871.0 26.40,  899.0 26.73, 927.0 26.78, 1038.0 27.74,
@ 1149.0 29.15, 1288.0 30.38
*Steel cp(T) from Abrahams, 1978
5
    19.9  467.0,   38.0 471.0,   73.0 484.0,  149.0  501.0,
@  204.0  518.0,  260.0 536.0,  316.0 558.0,  371.0  580.0,
@  427.0  606.0,  482.0 641.0,  538.0 690.0,  593.0  736.0,
@  649.0  777.0,  677.0 810.0, 704.0 1098.0,  732.0 1410.0,
```

```
@  760.0 1012.0,  788.0 727.0,  816.0 568.0,  843.0  535.0,
@  871.0  522.0,  899.0 533.0,  927.0 568.0, 1038.0  584.0,
@ 1149.0  598.0, 1288.0 610.0
*PVC Cp
15
   18.0    950.0,  87.0  1457.0, 107.0 1569.0,  500.0  1569.0
35
   0.0    12640.0, 546.0 12640.0,  547.0 0.0,  1000.0 0.0
* Flux: A-pump fire, A-train cable tray target
* +1.7 kW/m2 applied prior to layer reaching critical elevation
510
*See Figure A-17
* End exposure
* Temps: A-pump
* ambient temps prior to layer reaching critical elevation
515
*See Figure A-14
NODES MONITORED
10  1  6
TRANSIENT
2  1200.0
0.99 1.0e-4 2 1.0e-4 0.0 0.0 1 12 1
0.05 1.0 2.0 99999.0 0.0 0.0 0.01
%
```

A.9 Sprinkler System Actuation Calculations

A.9.1 Background

The sprinkler system actuation time is a useful parameter for assessing the potential for a fire to impact at target. Sprinkler actuation times are typically determined using programs such as DETACT [Portier et al., 1996]. When performing such a calculation, the input requirements generally include the location of the sprinkler relative to the source fire, the sprinkler actuation temperature, and the Response Time Index (RTI), a parameter that characterizes the sensitivity of the sprinkler to a temperature increase.

DETACT is a useful tool for calculating sprinkler actuation provided the configuration that is modeled is appropriate relative to the underlying assumptions. DETACT assumes that the sprinkler is heated and ultimately actuates by the thermal plume if the sprinkler is located near enough to the fire axis. Otherwise, DETACT assumes that the sprinkler is heated by an unconfined ceiling jet [Alpert, 1972; Portier et al., 1996]. When using DETACT, the fire must be located away from walls and corners, and there may not be obstructions (*i.e.*, bays, steel elements, and cable trays) that could interfere with the thermal plume or ceiling jet. The scenarios modeled in the SWIS involve fires located in corners and against walls. Further, the sprinklers are located in and around bays formed by the structural concrete, and the bays often contain considerable numbers of obstructions such as ducts, cable trays, and pipes. As a result, the use of DETACT was not considered appropriate for calculating the sprinkler response in the SWIS. A customized approach for bracketing the sprinkler response time in the SWIS is presented below.

A.9.2 Sprinkler Actuation Calculation

Sprinkler actuation in the SWIS was assessed by solving the following equation [Schifiliti et al., 2002]:

$$\frac{dT_s}{dt} = \frac{U^{1/2}(T_g - T_s)}{RTI} \qquad \text{(A-26)}$$

where T_s is the sprinkler actuation element temperature (°C [°F]), t is the time (s), U is the local air velocity (m/s [ft/s]), T_g is the local air temperature (°C [°F]), and RTI is the Response Time Index of the particular sprinkler ($m^{1/2}$-$s^{1/2}$ [$ft^{1/2}$-$s^{1/2}$]).

The sprinkler is assumed to actuate when T_s exceeds the temperature rating of the sprinkler. When solving Equation A–26, the average air temperature is typically a known quantity. This is obtained from CFAST or from plume correlations specific to the configuration (*i.e.*, corner fire). The local air velocity is typically an unknown parameter. However, several inferences may be drawn regarding the maximum and minimum potential local air velocity and with this, an actuation time range results.

For the purposes of this analysis, a still condition is assumed to be approximately 0.1 m/s (3.3 ft/s). Because the smoke layer is expected to be turbulent with constant agitation from the fire, it is not credible to postulate a local velocity lower than this, otherwise the smoke layer would be completely stagnant and would stratify by temperature.

An upper bound on the velocity is estimated from the velocity of typical thermal plumes in spaces with similar ceiling heights. The centerline velocity in an unconfined (open) thermal plume is given by the following equation [Beyler, 1986]:

$$\begin{aligned} U_m &= 1.1\dot{Q}^{1/3}(Z - \Delta z)^{-1/3} \quad (SI) \\ U_m &= 2.5\dot{Q}^{1/3}(Z - \Delta z)^{-1/3} \quad (English) \end{aligned} \qquad \text{(A–27)}$$

where U_m is the centerline velocity above an unconfined thermal plume (m/s [ft/s]), $\dot{Q}$ is the convective heat release rate (kW [Btu/s]), Z is the elevation above the base of the fire at which U_m is calculated (m [ft]), and Δz is the height of the point source heat release rate that would produce a similar thermal plume to that which is burning (m [ft]). The velocity varies with distance from the centerline of the axis of the fire in the following manner [Beyler, 1986]:

$$U(r) = U_m \exp\left(-\frac{r^2}{b_u^2}\right) \qquad \text{(A–28)}$$

where $U(r)$ is the velocity (m/s [ft/s]) within the thermal plume at a horizontal distance r (m [ft]) from the thermal plume axis and b_u is the width (m [ft]) of the thermal plume at the elevation considered. For the purposes of this calculation, only a rough estimate of the average velocity at the ceiling near a sprinkler is desired. As such, Δz is assumed zero and the convective heat release rate is assumed to be eighty percent of the total heat release rate [Tewarson, 2002]. The average thermal plume velocity at a particular elevation is obtained by integrating equation A–28 and then dividing the result by the diameter of the thermal plume, or 2 x b_u. The average plume velocity is then:

$$\overline{U} = 0.88U_m \qquad \text{(A–29)}$$

where $\overline{U}$ is the average velocity (m/s [ft/s]) of the thermal plume at an elevation Z (m [ft]) above the base of the source fire. The actual integration of Equation A–28 was performed using negative infinity and positive infinity as limits. Because Equation A–28 is not zero when r equals b_u, Equation A–29 somewhat overestimates the average thermal plume velocity.

Based on the results in Section A.3, the heat release rate of the various fire scenarios ranges form 350 kW (332 Btu/s) to 5,420 kW (5,120 Btu/s). The resulting convective portion of the heat release rate ranges from 280 kW (265 Btu/s) to 4,340 kW (4,110 Btu/s). The sprinkler elevations range from about 5 m (16 ft) to about 10 m (33 ft) above the floor. The calculated centerline plume velocity using Equation A–27 then ranges from about 4.2 m/s (13.8 ft/s) to over 10 m/s (33 ft/s). The average plume velocity, calculated using Equation A–28 is thus between 3.7 m/s (12.8 ft/s) and over 8.8 m/s (28.8 ft/s). Note that this calculation does not consider the impact of the ceiling and assumes that the plume is unconfined. Centerline velocities may be greater than the estimated range for actual SWIS configurations.

It is therefore reasonable to assume that as a minimum, U in Equation A–26 will fall between 0.1 m/s (0.3 ft/s) for relatively stagnant conditions remote from the fire to over 2 m/s (6.6 ft/s) or greater in areas local to the fire.